The practice of interdisciplinary design in Building Information Modelling (BIM)-enabled projects: A workplace study

by

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ABSTRACT

Building Information Modelling (BIM) is believed to enable significant efficiency improvements in interdisciplinary design in construction. This is mainly based on the rhetoric of BIM dominated by promoting its capabilities for data transactions. However, literature shows that there are problems in applying BIM technologies in practice, because their use causes unanticipated shifts in the focus and organisation of design projects. Furthermore, changes wrought by applied BIM technologies transcend the boundaries of the organisation of individual projects, and displace the previous ethos of 'professionalism' in design in construction. Consequently, there is unresolved confusion and evaluation about BIM technologies in terms of the nature and extent of the change they create. The present research aims to develop a better-informed understanding of BIM-driven change in design in construction through an empirical study of '*organising*' and '*order*' in BIM-enabled interdisciplinary design projects.

Using a practice-based methodology, this research focused on the interdisciplinary interactions during three projects. A practice-based methodology sees '*organising'* and '*order'* as continuously accomplished through the ongoing activities that are performed in practices. Therefore, the research scrutinised the interdisciplinary activities and processes which look mundane but enable *'organising'*, and *'order'* in the studied projects. Three explanatory organisational concepts are developed through the analyses of the empirical data: '*organisational premises*', '*purposeful artefact*', and '*technological premises*'. These concepts provide three different explanations about how *'organising'* interdisciplinary design in BIM-enabled projects is accomplished through the ongoing interdisciplinary activities performed in practices. Thus, they produce a rich understanding of the complex organisational phenomena. Interdisciplinary design development is then seen as a '*continuous process of (re-)establishing a shared sense of purposefulness'* among the members of a design team, which largely depends on previous shared experiences. This continuous requirement for mutual dependency does not align well with the operational characteristics of BIM technologies, which are fundamentally planned and rigid. Therefore, practitioners experience divergent views of '*organising'* (i.e. and '*work*') in BIM-enabled projects. The '*ordering'* induced by BIM technologies appears in the interface of these different views of *'organising'* (and '*work'*), as it is here that practices unfold, and become directed towards one or other view. In such cases, the extent to which information modelling and design development can be prioritised is determined by the level of reliance on technology, and the level of authority of those individuals who are in control of the BIM technologies.

The practice-based understandings of '*organising'* and '*order'* that emerge from the analyses are used herein to refine the notions of 'design', 'design collaboration', 'use of information and communication technologies (ICT) in construction design', and 'ICT-driven change in construction design'. Thus, the practice-based methodology reveals that some of the main arguments upon which the promotional rhetoric of BIM is founded are incomplete or flawed. Through its methodological and theoretical contributions, the present research evaluated BIM-driven change in design in construction, and created an agenda for further critical and practically-relevant studies into interdisciplinary design in construction. This shows the need for further research which should re-establish the use and development of BIM by aligning it with the realities of actual practice.

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DEDICATION

TO ALL THOSE WHO HAVE THE COURAGE AND WISDOM TO QUESTION THEIR QUESTIONS…

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CHAPTER 1. INTRODUCTION

1.1. Rationale of the Research

> *"Order is, at one and the same time, that which is given in things as their inner law, the hidden network that determines the way they confront one another, and also that which has no existence except in the grid created by a glance, an examination, a language; and it is only in the blank spaces of this grid that order manifests itself in depth as though already there, waiting in silence for the moment of its expression" (Foucault 2005/1966: xxi).*

The effects of contemporary information and communication technologies (ICT) on the way work is organised can be argued to be revolutionary. Yoo (2013) claims that products and services that rely on programmable digital technologies that are connected to internet are changing the characteristics of economics throughout the world. The 'generativity' (e.g. Eck et al. 2015) of contemporary ICT, which is "*a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences*" (Zittrain 2006: 1980), has significantly increased over the last fifteen years. Thus, contemporary technologies have driven changes in division of labour, the understanding of the concept of 'work', and eventually organisation of 'work' (Kallinikos 2006; Yoo 2013; Constantiou & Kallinikos 2015). As Barley (1996: 404) aptly puts it: "*history tells us that technology, organization, and work co-evolve*"; and no organisational structure can be optimal unless it is tailored to the technology and the work it seeks to systematise (Barley 1996).

There is a general tendency to associate the rapid pace of technological advances with innovation and positive change. However, there are also concerns about the dominant view of 'innovation' that intimates that novelty is always good (Suchman & Bishop 2000), and about the arguably negative effects of ICT that can emphasise certain categories of thinking, and favour them over others, thus, making ICT an ethical consideration (Star & Bowker 2007). Similarly, it has also been argued that ICT's operational principles are based on 'limited and selective objectification' of properties or facets of the world for survey and control (Kallinikos 1995). Hence, there are views that claim that "*at least as much is lost as it is gained*" (Kallinikos 2012: 83) in the ongoing global trend of digitalisation, thus justifying critical examination of the effects of contemporary ICT on work.

Historically, the construction industry has been criticised for being wasteful and inefficient, and so it has been embracing technological innovations such as new construction materials, physical technologies (e.g. machinery), or ICT for improvement. However, industry reports and evaluations of the industry have continued to be critical about its performance. Over the last few decades, one of the main debates about the inefficiency in the construction industry has been based on the fragmentation and adverse relationships among the various actors (e.g. Latham 1994).

In these global and industrial contexts, Building Information Modelling (BIM) has received increasing interest from software vendors, scholars, national and international policy makers, and practitioners, fuelled by the promotional rhetoric developed around it. The 'BIM utopia' (Miettinen & Paavola 2014) that has developed over time, has had the tendency to emphasise the capabilities of the technologies introduced under the umbrella term of 'BIM'. This meant a tendency to formulate all activities and challenges in construction around computer-friendly concepts of 'computable information' (i.e. data) and 'business process', which have aimed to neatly categorise and structure the world of 'messy' practices (Dossick & Neff 2011). In academia, a significant amount of research effort has focused on improving the capabilities of BIM technologies (Xue et al. 2012), and drawing direct linkages between technological capabilities and performance increases (e.g. Shen et al. 2010). However, it has also been argued that processes and human issues need to be considered for the successful adoption of BIM (Arayici et al. 2011). This has been generally understood as the need for adjustments by people and organisations to the capabilities of technology, thus, reflecting a 'technology-push approach' (Hartmann 2012). However, the technology-centred approaches, which formulate and seek to resolve all challenges in construction work through structuring business processes and ICT-mediated data exchanges, are deemed inadequate because they oversimplify the complex phenomena that take place in the construction industry (Harty 2008; Harty & Whyte 2009; Berente et al. 2010). Furthermore, studies have suggested that the shift that has been taking place in construction due to BIM needs to be understood beyond its effects on individual projects or the structure of companies. It has been shown that BIM indeed causes shifts in perceptions on the life-cycle of buildings (Love et al. 2014), professional roles (Sebastian 2011) and even the meaning of 'professionalism' (Jaradat et al. 2013) in the construction industry. In this sense, the industry has been trying to make sense of the nature and effects of the change that BIM has brought about.

Consequently, it can be argued that it is timely and necessary for construction management scholars to direct their efforts to develop further insight into the transformation of the complex relationships between technology, organisation and work, fuelled by BIM. This present research therefore considers 'order' in BIM-enabled projects, embracing the significantly different nature of the technologies that BIM introduces to the construction industry. The unprecedented features of these technologies provide an interesting context to investigate 'order' in a selected domain of work; 'interdisciplinary design in construction' is the focus for this research. Nevertheless, 'order' is one of the main interests of study of social theory, and there are various ways of studying it based on a variety of philosophical, theoretical and methodological assumptions (see for example Turner 2009).

In this study, a 'practice-based approach' (Schatzki 2001; 2002; Orlikowski 2010; Gherardi 2012; Nicolini 2012) is adopted to study the organisational phenomena and order in BIM-enabled interdisciplinary design projects. Practice-based approach is unique in its view of 'organising' and 'order' as continuously accomplished through the ongoing activities that are performed in everyday practices (Schatzki 2001; Gherardi 2012). According to this approach, structures and routines of organisations are the patterns of activities that can be identified, but they are rooted in, and continuously re-produced through the performances in everyday practices (Feldman & Orlikowski 2011). Consequently, a practice-based approach implies an empirical interest in the activities and processes which look mundane in order to provide explanations about 'organising' and 'order' (Orlikowski 2010). The decision of adopting a practice-based approach for this research and focusing on the performances that constitute everyday practices mainly relies on the lack of widely accepted, and practically relevant conceptualisations for understanding BIM-enabled interdisciplinary design in construction.

It has been argued that, prior to BIM, the exchange of design information among various members of design teams had been problematic, resulting in repeating work, information loss and coordination problems (e.g. Zaneldin et al. 2001). In this respect, data management and presentation capabilities of BIM technologies have been argued as enablers of better design and design collaboration (Shen et al. 2010; Xue et al. 2012). Nevertheless, the studies that promote the adoption of BIM technologies for improved design collaboration have been criticised for not being practically relevant (e.g. Shelbourn et al. 2007; Achten & Beetz 2009). Empirical research has shown that there are problems in practice with fulfilling the promoted capabilities of use of BIM technologies (e.g. Harty 2008; Dossick & Neff 2010), and some researchers argue for critical and practically relevant conceptualisations of BIM technologies in design in construction (e.g. Whyte 2013). Moreover, both 'collaboration' (Bedwell et al. 2012) and 'collaborative design' are disputed concepts, and there is no agreement in the literature about what constitutes 'collaborative design' (Kvan 2000; Achten & Beetz 2009; Wang & Oygur 2010).

In addition to the lack of understanding of interdisciplinary design work at practice level, there is also lack of agreement about what constitutes 'the construction industry' as an organisational whole (Bygballe et al. 2013), and design in construction more specifically (Kvan 1999; Zerjav 2012). The limited number of studies into the way the construction industry works reveal that activities and organisation of work have significant peculiarities (e.g. Dubois & Gadde 2002; Fernández-Solís 2008), which suggests that it is not appropriate to employ concepts developed elsewhere without a critical and empirical examination of their applicability. Construction work is complex and involves disparate perspectives. Any attempt for operational improvements requires an adequate understanding of the interactions both within a range of actors, and between the actors and technology (Harty 2005; 2008). Finally, the concept of 'design' is itself disputed (Coyne 2005), and some argue that the scope of design as a professional undertaking is subject to change due to the global trend of digitalisation (Yoo 2012).

In the light of these conceptual and theoretical problems in interdisciplinary design work in construction, the present research studies 'organising' and 'order' from a practice-based point of view rather than utilising disputed high-level constructs such as 'design', 'technology' or 'collaboration'. This sets the level of inquiry as activities performed in everyday practices to explore i) how meaning is achieved through the interactions of people, design artefacts[1], and building information models in practice (i.e. organising); and ii) why the things are done the way they are (i.e. order). This approach has significant implications on the way 'theory', 'methodology' (i.e. data collection, data analysis and writing-up processes) and 'practice' are considered, and therefore, deserves a brief explanation regarding the relationships between these three elements.

Drawing on Orlikowski (2010), this study considers 'practice theory' in relation to the following three ways of studying 'practice' (i.e. empirical phenomena): an empirical orientation to exploring how people act in organisational contexts; a theoretical orientation to understanding relations between the actions people take and the structures of organisational life; and a philosophical orientation on the constitutive role of practices in

[1] In this study, the notion of 'design artefact' is used in a particular sense. In this study, 'design artefacts' refer to all objects that are created and / or used in interdisciplinary design work. According to the practice-based view of organising adopted in this research, design artefacts do not only contribute to the accomplishment of interdisciplinary design through their representational contents. They also have intermediary, and performative roles which are essential for the ongoing accomplishment of organising. Further explanation regarding such view of 'design artefact' is provided in the Section 2.3.2.3 of Chapter 2 - Literature Review.

producing organisational reality (Feldman & Orlikowski 2011). Such a definition of 'theory' seems in contrast with the general view of 'a theory' which can be defined as "*a formal system of hypotheses that generate explanations and predictions*" (Stern 2003: 187), because 'practice theory' corresponds rather more to a "*systematic way of approaching a given subject matter*" (Stern 2003: 187). In order to emphasise this unique aspect of 'practice theory', some other expressions such as 'practice lens' (e.g. Feldman & Orlikowski 2011), 'practice thinking', and 'practice approach' (Schatzki 2001) are used interchangeably with 'practice theory' both in the literature and in this study. In line with this unique understanding of theory, there is no unified practice approach (Schatzki 2001) and 'practice theorists' are an unusually diverse group (Stern 2003) in their fundamental conceptions, such as those about activities and agency (Schatzki 2001). Nevertheless, some fundamental shared sensitivities can still be identified among different practice-based approaches that justifies their grouping under some umbrella terms (Nicolini 2012). A discussion about the empirical, theoretical and philosophical orientations that underpin this research are provided in Chapter 3 - Methodology, following a general introduction to 'practice thinking' in the first main section of Chapter 2 – Literature Review.

A practice-based research approach as outlined above is adopted to capture the studied empirical phenomena of interest, without being bounded with certain definitions of the disputed high-level 'constructs' (i.e. design, collaboration, technology). It has been argued by Gioia et al. (2013) that for organisational studies to fulfil their potential for description, explanation, and prescription, it is first necessary to develop 'concepts' that capture the qualities that describe or explain the phenomenon of theoretical interest, so that related higher level 'constructs' can be created and validated. Therefore, it is necessary and timely to engage in the task of developing practically relevant conceptualisations of BIM-enabled design practices to be used to inform discussions about the change taking place in construction design. In this regard, a practice-based exploration of 'organising' and 'order' in BIM-enabled interdisciplinary design projects is necessary to refine the understanding of higher level constructs that are essential to grasp and direct the ongoing change. This is crucial because the increasing use of digital technologies in built environment practices in the absence of practically-informed discussions, risks creating more problems than solutions and more confusion. As highlighted by Miettinen and Paavola (2014) the understanding about technology-driven change that the construction industry has been undergoing must not be detached from practical realities. The present researcher supports this argument, and hence the present research aims to expose and discuss the variety of the perspectives that the practitioners have about the ongoing change with the ultimate purpose of driving informed positive developments in construction design.

Therefore, this research can be categorised, as a 'workplace study' (Luff et al. 2000a; Heath et al. 2000; Llewellyn & Hindmarsh 2009) which makes collaboration and technology the central themes of investigation (Nicolini 2012). Although workplace studies have been extensively employed to develop better understanding of mundane - but complex - workplace activities to enable better ICT design, their principal contribution is in reshaping the ways in which every day social actions, interactions and technologies are conceived in the workplace (Luff et al. 2000b). According to Luff et al. (2000b: 12) "*perhaps the more immediate contribution of workplace studies is in outlining the conceptual and methodological innovations required in the social sciences to understand the ways in which artefacts and technologies are utilised in everyday workplaces*". The rationale of the present research is commensurate with this ethos put forward by Luff et al. (2000b) because it advocates for novel and practically relevant conceptualisations of technology use in interdisciplinary design work in construction.

Through the 'ethnographic sensitivities and sensibilities' (Brannan et al. 2007) adopted in data collection and analysis, this research aims not only to provide new concepts and perspectives about the practicalities of ICT use in interdisciplinary design in construction, but it also delineates the 'work' that goes into establishing and maintaining a design project organisation in construction. Therefore, the present research gives a voice to mundane everyday activities through which 'organising', 'order', and therefore the 'ICT-driven change' in design in construction have been brought about in certain ways. The quote at the beginning of this section implies that 'order' is not pre-determined or real until it is enacted through "*a glance, an examination, a language*". It is the intention of this research to lay the foundations of an 'order' that considers the pluralism inherent in built environment practices through the ethnographical *examination* that it undertakes, and the new *language* that it develops in the form of practice-based concepts and discussions. Hence, the present research provides both an explanation of, and a direction for the BIM-driven change in design in construction.

1.2. Preliminary Research, the Aim Statement, and the Research Questions

Before starting the ethnographic study, the researcher conducted interviews with professionals from the Birmingham, UK office of a multidisciplinary engineering company. The company has been established for forty years in the UK, and now operates in twenty locations around the world with over four hundred staff. The interviews took place four months after the beginning of the study, and therefore they were conducted after an initial literature review on ICT and their effects on organisations. The interviews were semi-structured and lasted between thirty minutes to one hour each. They were conducted with an associate partner, two mechanical engineers, two energy-modelling engineers, one structural engineer and one acoustic engineer. The interviews aimed to gain insight into the changes that occurred with the implementation of BIM, and about practitioners' perceptions of BIM. The interview questions for the preliminary research can be found in Appendix 1.

The major finding of this preliminary research was the variety of the ways different professions perceived and used technologies of BIM in their work. For instance, it was found that the kinds of changes occurring in the everyday practices of mechanical engineers were different from those of the structural engineer. Moreover, the interviewed practitioners had doubts about the advantages of the extra effort they had been spending on modelling because they believed that the contractors still did not use the models in the construction phase. Nevertheless, BIM technologies were in place and being used, certainly not in a standardised way, but in an improvised way. There was a pragmatism in the use of BIM technologies which was justified by the specific conditions and requirements of i) the design firm, ii) the projects that needed to be delivered, and iii) the professions that had been using these technologies. It was this 'practical approach' to BIM technologies which overarched various perspectives and uses of them, thus, producing a bespoke 'order' stemming from the ongoing interdisciplinary interactions. The present researcher found that most of the concerns and practices articulated by the interviewees were under-explored and under-theorised in the construction management literature. The findings of this preliminary research are published in a conference paper (Çıdık et al. 2013 - see Paper 1 in Appendix 3).

Therefore, the findings of the preliminary research, and the review of the extant literature on the ICT use in interdisciplinary design in construction projects, implied a research challenge that can be stated as:

> '*the need for practically relevant conceptualisation of interdisciplinary design work in BIM-enabled construction projects'*.

This challenge is of crucial importance to appreciate and direct the ICT-driven change that the construction industry, in general, and the design in construction in particular, have been undergoing. Consequently, the aim statement of this study can be articulated as:

> '*to develop an understanding of the change in interdisciplinary design in construction that has been fuelled by technologies of BIM with the purpose of enabling a better informed engagement'*.

In addressing the above, the researcher conducted a longitudinal, ethnographic field study during which understanding of the phenomena of interest, and knowledge about previous literature constantly developed. This can be seen as an iterative process moving continuously between the object of study and previous relevant literature. Therefore, the research process was dynamic in the sense that it was driven by the developing insights of the researcher based on both his aggregating experiences on the field and his developing knowledge gained from the literature (e.g. Van Maanen 2011; Gioia et al. 2013).

Ethnographic research requires its findings to be presented through a text that is tailored according to its audience (Jordan 1996). In consideration of this, the presentation of the findings and analyses of the present research are structured around a set of research questions. These research questions were formulated as part of the data analysis/writing-up processes (see Sections 3.4.3 and 3.4.4 in Chapter 3), and they both reflect the evolving frame of inquiry of the researcher during the ethnographic fieldwork, and provide an analytical structure which enables the principal argument that is put forward in the present study. The details about the selection and formulation of the research questions, and how they are used to devise different empirical foci for the description and analysis of rich empirical data are discussed in Section 3.3.2 (Chapter 3).

- *Research Question 1:* How is interdisciplinary design work accomplished in practice in BIM-enabled projects? How do people make sense of developing the design together in interdisciplinary design projects?
- *Research Question 2:* What is the role of design artefacts (see Footnote 1) in the practical accomplishment of interdisciplinary design development?
- *Research Question 3:* How is interdisciplinary model-based working accomplished in practice? How do people make sense of interdisciplinary model-based working?
- *Research Question 4:* What are the connections between model-based working practices and other interdisciplinary efforts?

The present research explores how '*organising*' is accomplished in the observed projects through addressing the research questions listed above based on the findings from the fieldwork. This also provides a practice-based footing for discussing the accomplishment of ‘*order*’ in BIM-enabled interdisciplinary design projects in construction. The practice-based conceptualisations of ‘*organising*’ and ‘*order*’ are then used to critically discuss the notions of ‘design’, ‘design collaboration’, ‘ICT use in design in construction’, and finally ‘ICT-driven change in construction design’.

1.3. Outline of the Thesis

This study is constituted of eight chapters as detailed below.

Chapter 2 is a literature review, consisting of three main sections, in addition to an introductory section. The first main section introduces the theoretical and philosophical background of practice-based view of organising and order. This focuses on the notions of ‘knowing’ and ‘organising’ considering both the knowledge-intense nature of design work, and the practice-based view of knowing which corresponds to ‘knowledgeability’. Second and third main sections in Chapter 2 establish the contextual background of the research. The second main section introduces some of the major debates on the nature of design in general, and on the organisation of interdisciplinary design work in construction in particular. This is followed by the third main section which introduces previous work on BIM, interdisciplinary design, and technology in organisations.

Chapter 3 is the methodology chapter. It develops the arguments about the philosophical, theoretical and empirical orientations of this research that result from the adopted practice-based approach. It starts with establishing the philosophical orientation of the research. The identified challenges of the investigation are there related to the adopted ontological/epistemological assumptions made. The chapter then discusses the theoretical orientation of the research, and explains how ‘practice thinking’ is used for theory building including an in-depth explanation of the role of different research questions devised for each of the findings and analysis chapters (i.e. Chapters 4, 5, and 6). Finally, the chapter establishes the empirical orientation of the research by providing detailed explanations and discussions about the research process with a focus on the data collection, data analysis, and writing-up processes that were followed.

Chapters 4, 5 and 6 are the findings and analysis chapters. Each is governed by different research questions, and provides a valid, self-contained, individual narrative about organising the observed projects through focusing on a different set of activities and processes. Chapter 4 addresses ‘Research Question (RQ) 1’. (How is interdisciplinary design work accomplished in practice in BIM-enabled projects? How do people make sense of developing the design together in interdisciplinary design projects?). The chapter focuses on the 'oriented and concerned nature' of the observed interdisciplinary design development practices in order to establish how practitioners make sense of what to do, and what ought to be done in interdisciplinary design development. A concluding discussion in Chapter 4 develops an explanatory organisational concept to answer RQ 1, and presents the rationale for further investigations that are presented in Chapters 5 and 6.

Chapter 5 seeks to tackle RQ 2. (What is the role of design artefacts in the practical accomplishment of interdisciplinary design development?). It focuses on the 'active role of design artefacts' in interdisciplinary design development practices. The chapter presents findings about the three main types of situations in which design artefacts appear in interdisciplinary design development practices. The chapter ends with a theoretical discussion through which another explanatory organisational concept is developed to answer RQ 2.

Chapter 6 explores RQ 3. (How is interdisciplinary model-based working accomplished in practice? How do people make sense of interdisciplinary model-based working?); and RQ 4. (What are the connections between model-based working practices and other interdisciplinary efforts?). The chapter focuses on the 'oriented and concerned nature' of interdisciplinary model-based working to establish how practitioners make sense of what to do, and what ought to be done in interdisciplinary model-based working. Like Chapters 4 and 5, Chapter 6 also ends with a theoretical discussion through which a third explanatory organisational concept is developed to answer the explored research questions.

Chapter 7 is the discussion chapter. It consists of three main sections following an introductory section. The first main section discusses the practice-based understandings of 'organising' and 'order' that emerge from the findings and analyses of this research. This includes an account of the methodological choices made and how they contributed to exploring complex organisational phenomena in interdisciplinary design projects in construction. Having established practice-based understandings of 'organising' and 'order' in BIM-enabled interdisciplinary design projects, Chapter 7 then discusses the practice-based understandings of 'design', 'design collaboration', 'ICT use in interdisciplinary design' in construction in the second main section. In the final main section of the chapter an overarching discussion of 'ICT-driven change in construction design' is provided. This involves an engagement with previous empirical research on ICT and organising design in construction to delineate the disciplinary contribution made by the present research.

The last chapter, Chapter 8, summarises the study and reflects on its achievements and limitations. Theoretical, methodological and practical contributions of the study are delineated. The chapter ends with a reflection on the directions for future research.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

In this chapter, a review of the relevant literature is presented to establish the theoretical (in Section 2.2) and contextual backgrounds (in Sections 2.3 and 2.4) of the study. In line with the practice-based approach adopted in this research, this chapter does not extensively review the literature about the constructs relevant to the study (i.e. design, design collaboration, ICT in design) to reach refined views of them to be used for data analysis. Rather, the chapter has two main aims. The first aim is to introduce a theoretical understanding of the adopted practice-based view in terms of its conception of 'organising' and 'order' (see Section 2.2). The second aim is to establish a direction for the arguments that will be made in the thesis through a selected set of studies around the relevant constructs (see Sections 2.3 and 2.4). In setting the contextual background of the study, Sections 2.3 and 2.4 introduce some of the major debates around the relevant constructs and the different approaches employed for theorising about them. Discussion of studies that utilise a variety of theoretical and methodological approaches allows both rich understandings of these debates and the practice-based approach to be set in wider theoretical arena.

Most 'work' that is undertaken in the post-industrial era is not mainly characterised by physical activity. Non-physical work, including design work, can be thought as 'knowledge work'. However, 'knowledge' is an elusive concept that has troubled those who have researched how 'knowledge work' is organised. The practice-based view adopted in the present research provides an alternative conception of 'knowledge', which is directly related to 'organising'. From a practice-based point of view, there is no 'knowledge' that can be understood as a static concept. Rather, 'knowing' is understood as a process that enables 'knowledgeability' of how to act in practice, and thus, sustains ways of doing things. Consequently, the first main section of the chapter looks at 'knowing' and 'organising' to introduce the theoretical background of the adopted views of 'organising' and 'order'. In this respect, Section 2.2.1 makes the case for studying organisations through the concept of knowledge. Section 2.2.2 focuses and differentiates between two epistemologies of knowledge and corresponding views of organisation, thus, revealing the peculiarities of practice-based views of 'knowing' and 'organising'. Section 2.2.3 further focuses on practice-based view of organising interdisciplinary team work. It presents a selected set of practice-based studies which highlights various dimensions of practice-based views of 'knowing' and ‘organising’ that are essential to establishing and sustaining (i.e. organising) interdisciplinary team work.

The following two main sections of this chapter provide the contextual background for this study through reviewing a selected set of studies, and thus give a direction for the arguments that will be made. Section 2.3 focuses on the ‘theorisation of design, and organisation of design work’. In Section 2.3.1, a historical account of some of the most-employed views on the nature and process of design are introduced, exposing how they are fragmented and divergent both philosophically and methodologically. More specifically, what can be designed, who is entitled to design, and how the design process works, are shown to be central issues of ongoing debates. Having established that there are no widely agreed understanding of what constitutes design, Section 2.3.2 shifts the focus to understanding the views on organisation of design work in construction. It identifies that design in construction is mainly seen as compartmentalised and fragmented, and the ‘fragmentation-integration’ debate dominates the understanding of organisation of design work in construction. A review of the studies that contribute to this debate are presented in Section 2.3.2. These are grouped under the headings of ‘design management in construction’ and ‘design collaboration in construction’. Review of the literature under these categories reveals that research on organising interdisciplinary design in construction is dispersed, non-accumulative and confused in terms of its concepts (e.g. the use of the term ‘collaboration’). Section 2.3.2 also delineates the centrality of ‘design artefacts’ in organising interdisciplinary design work through examples of research that emphasise the intermediary and performative roles of design artefacts in addition to their representational aspects. This provides a deeper understanding of the practice-based view of design artefacts, which assumes that design artefacts have active roles in accomplishing the organisation of design work.

Finally, in Section 2.4 the focus shifts to ‘BIM, interdisciplinary design, and technology in organisations’. Section 2.4.1 starts with an overview of the dominant promotional rhetoric of BIM which claims that data management capabilities of BIM technologies are what the construction industry has needed for achieving more collaborative design. Nevertheless, these studies, which draw direct linkages between technological integration and ‘collaboration’, uncritically adopt a particular view of ‘collaboration’ which is framed around data transactions. Therefore, Section 2.4.1 continues with a review of the literature that criticises this technology-centred perspective through the exploration of the organisational challenges brought about by the adoption of BIM. This literature indicates that the relation between technological integration and efficiency increase in interdisciplinary work is not straightforward as the new technologies disrupt historically established organisational foundations, thus, resulting in unanticipated organisational challenges. This is followed by Section 2.4.2 which introduces a wider theoretical perspective on the interplay between technology and organising, so that the arguments presented in the preceding section can be set in a wider context. The arguments presented in this section provide conceptions about the effects of technology on organising at different levels (i.e. practice, organisational and inter-organisational), thus, complementing the arguments from the organisational research on BIM and interdisciplinary design presented in the preceding section.

Ultimately, this chapter sets the theoretical background that is used in setting and approaching the empirical phenomena of interest and its analysis (i.e. what is of interest from a practice-based perspective). This is further detailed in Chapter 3. Besides, this chapter also sets the contextual background of the study by introducing the major debates around the constructs relevant to organisation of design work in BIM-enabled projects (i.e. what is the state of the art, and what are the potential contributions that can be made).

2.2. Knowing and Organising

2.2.1. Introduction

'Knowledge' has been seen as of central and strategical to organisational phenomena since the 1970s (e.g. Drucker 1969; Kogut & Zander 1992; Nicolini et al. 2003; Newell 2015). Nicolini et. al. (2003) and Newell (2015) connect the increased interest in 'knowledge' in organisational studies to a wider trend that gradually built-up after the Second World War during the 'post-industrial era', or 'information age'. The claim is that (Nicolini et al. 2003; Newell 2015) the recognition of labour as more than physical work, and the value of intangible and intellectual assets in post-industrial economy have gradually occurred, and the signs of this can be seen in some pioneering works. For example, Galbraith (1967) shifted the meaning of the notion of 'competition' away from the production of goods; Drucker (1969) coined the term 'knowledge society'; Schön (1971) urged organisations to become 'learning systems' due to the continuous state of instability caused by ever-developing modern technologies; and Bell (1973) claimed that a new kind of society, a post-industrial society, was coming, and that it would be information-led and service-oriented. Hislop (2009) provides similar arguments and characterises the post-industrial society as service-driven, knowledge- and information-intensive, and as involving increasing need for theoretical knowledge in work (see Figure 1).

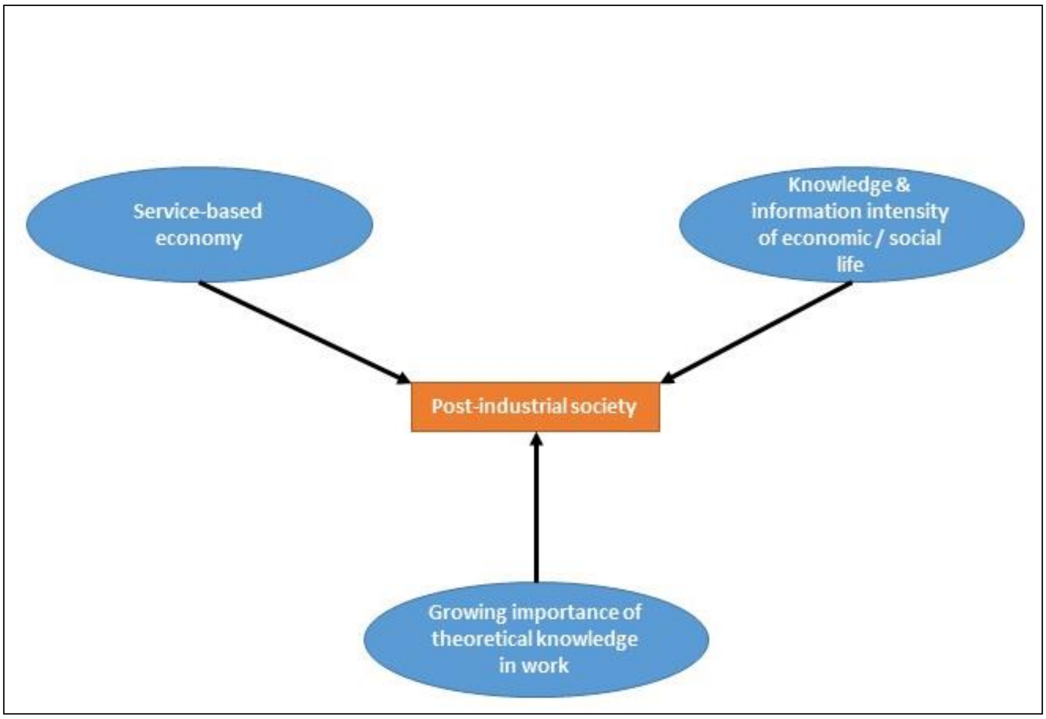

Figure 1 - Characteristics of post-industrial society (Hislop 2009)

According to Nicolini et al. (2003), one of the consequences of the growing interest in 'knowledge' in the post-industrial era has been on the organisational studies which showed itself as an increasing interest in 'organisational learning', 'knowledge creation' and 'knowledge management'. The concept of 'knowledge' became so central to the study of organisations that in the last decade of the 20th century, even a stream of research that theorised the firm as a knowledge-based organisation gained momentum in academia (e.g. Grant 1996; Kogut & Zander 1996). This theory challenged previous dominant views of firms and organisations. For example, according to Brown and Duguid (1998) this movement had risen to counter the transaction-cost view of the firm, which would argue that the new information and communication technologies might drive transaction costs so low that hierarchical firms will dissolve into markets of self-organising individuals. As opposed to the transaction-cost view of the firm, "*knowledge-based arguments suggest that organisational knowledge provides a synergistic advantage not replicable in the market place. Thus its knowledge, not its transaction costs holds an organisation together*" (Brown & Duguid 1998: 90). On the other hand, the increased interest in knowledge as a critical resource for organisations revealed that 'knowledge' was a problematic concept and it was difficult to be defined using the traditional categories of organisational analysis (Gherardi 2009).

Gherardi (2009) claims that the conceptual shift from 'organisation' to 'organising' that happened in 1990s corresponds to the shift from 'knowledge' to 'knowing' which happened around the same times, as can be seen in Blackler (1995). The difference between exploring organisational phenomena through the concept of 'knowledge' and the concept of 'knowing' is formulated by Cook and Brown (1999) concerning the different epistemologies attributed to them. Cook and Brown (1999) argue that treating 'knowledge' as an object of possession is insufficient in explaining the practices, and therefore an appreciation of 'knowing' which is based on epistemology of practice is required to complement it. As Cook and Brown (1999: 381) put it:

> "*Much current work on organizational knowledge, intellectual capital, knowledge-creating organizations, knowledge work, and the like rests on a single, traditional understanding of the nature of knowledge. We call this understanding the 'epistemology of possession,' since it treats knowledge as something people possess. Yet, this epistemology cannot account for the knowing found in individual and group practice. Knowing as action calls for an 'epistemology of practice'… We hold that knowledge is a tool of knowing, that knowing is an aspect of our interaction with the social and physical world, and that the interplay of knowledge and knowing can generate new knowledge and new ways of knowing*"

The notion of 'knowledge' as something people *have* (Blackler 1995), it being a cumulative stock, an asset that can be acquired and transferred (Uusitalo 2015: 22) corresponds to the epistemology of possession (Cook & Brown 1999). According to Hislop (2009), this is the objectivist view of knowledge. On the other hand, those who adopt a practice-based view of 'knowing' (and learning) in organisations refuse both the 'mentalistic' vision of knowledge, which claims that the knowledge resides in the heads of individuals, and its treatment as a commodity which can be moved around unproblematically (Gherardi 2000). Those who adopt a practice-based view of 'knowing' see the notion of 'knowledge' as something people *do* (Blackler 1995). The difference between the objectivist and practice-based views of knowledge is articulated by Newell (2015: 8) as a "*distinction [that] differentiates between the idea that people 'have knowledge' and that people 'act knowledgeably'*". The differentiation between the objectivist perspective (i.e. epistemology of possession) and practice-based view (i.e. epistemology of practice) of knowledge provides a useful point of entry to the practice-based view of 'knowing' and 'organising' through the contrasts between the two (e.g. Hislop 2009; Newell 2015; Uusitalo 2015). Therefore, in the next section, first a brief account of the objectivist view of 'knowledge' is presented, followed by a more-detailed account of the practice-based view of 'knowing'. These views of 'knowledge' and ‘knowing’ are then related to the corresponding views of organisation (i.e. knowledge-based theory of the firm/organisation, and knowing-in-practice respectively).

2.2.2. Epistemologies of knowledge, and corresponding views of organisation

According to Hislop (2009: 19) the objectivist view of knowledge is characterised by the following aspects:

- Knowledge is an entity/object;
- It is based on a positivistic philosophy where knowledge is regarded as objective ‘facts’;
- Explicit knowledge (objective) is privileged over tacit knowledge (subjective);
- Knowledge is derived from an intellectual process.

Hislop (2009: 19) argues that “*within the objectivist view of knowledge, the entitative character of knowledge represents its primary characteristic*”. Schultze (1998) calls this the ‘functionalist paradigm’ and states that those who adopt this paradigm assume that knowledge can be captured, manipulated, transferred, and protected thanks to its ‘object-like’ nature.

Under this perspective, there is a tendency to categorise and classify different types of knowledge in order to develop corresponding suitable procedures to manage various kinds of knowledge efficiently (Schultze 1998). Tsoukas (1996) names the researchers who adopts this perspective ‘taxonomists’ due to the categorical boundaries they impose on the organisational knowledge, which assumes that various knowledge phenomena can be conceptually categorised as distinct, separate and stable. According to Schultze (1998), the studies that adopt a functional view of knowledge devise categories of knowledge based on the i) location of the knowledge – such as individual, group, organisational knowledge (Hedlund 1994); ii) form of the knowledge – such as explicit and tacit knowledge (Nonaka 1994); iii) applicability of the knowledge – such as universal or local knowledge (Spender 1996); and iv) content of the knowledge – such as declarative and procedural (Kogut & Zander 1992) or ‘know-what, know-why, know-how’ (Wikstrom & Norman 1994).

Related to this, there are claims from the objectivist perspective that suggest that transition between different kinds of knowledge is possible and desirable for the management of the knowledge (Nonaka & Takeuchi 1995), and some categories of knowledge (e.g. explicit or ‘know-what’) can exist independently from people in a codified form (Cowan et al. 2000). Hislop (2009: 30) states that in the objectivist view of knowledge, “*sharing of knowledge* *between people has the characteristics of a 'transmitter-receiver' model, where it is assumed codified, explicit knowledge can be transferred from one person to other unmodified*". Therefore, according to this perspective, the codified knowledge is manageable or at least can be leveraged through the use of information technology, thus, granting a central position to information technologies in knowledge management (Zack 1999). Schultze and Leidner (2002) showed that Information Systems research that had studied knowledge management had been biased, and more than half of the papers that they reviewed, which were published between the years 1990 – 2000, adopted an objectivist (i.e. functional) view of knowledge. Arguments about codification of knowledge and leveraging its management through information technologies also imply a questioning of the differences among data, information and knowledge (e.g. Vance 1997). Under the objectivist view of knowledge, clear distinctions between them have been attempted based on a hierarchical view in which data is at the bottom waiting to be put in context or interpreted to become information or useful knowledge (Tuomi 1999; Alavi & Leidner 2001).

According to Hislop (2009), the knowledge-based theory of the firm is compatible with the objectivist view of knowledge and reflects similar assumptions in explaining organisational principles. Knowledge-based theory of the firm is a research stream that provides explanations about the reason for existence and organisational principles (e.g. boundaries) of the firms in terms of the dynamics of the knowledge processes they involve (e.g. Kogut & Zander 1992; Grant 1996). For example, Grant (1996) argues that the primary role of the firm is to integrate the specialist knowledge of individuals into goods and services through a careful coordination effort that considers various types of knowledge (e.g. tacit and explicit knowledge). Nickerson and Zenger (2004) criticise the previous focus on knowledge exchange and argue for a focus on knowledge production, and the alignment of knowledge-based theory of the firm with the view of the firm defined by its transaction costs. In this respect, they identify three governance modes for supporting knowledge formation based on the categorisation of the knowledge required to solve the kinds of problems that a firm confronts (Nickerson & Zenger 2004). Hislop (2009) claims that the knowledge-based view of the firm is compatible with the objectivist view of knowledge because i) it sees knowledge as an object; ii) it claims that there are separate and distinct types of knowledge (e.g. as can be seen in Grant 1996); iii) it sees knowledge as measurable and quantifiable; and iv) it shares the positivistic philosophy of the objectivist view of knowledge in drawing cause-effect relationships around knowledge-management issues (as can be seen in Nickerson & Zenger 2004).

On the other hand, studies that adopt an epistemology of practice, or a practice-based view of 'knowing' see the knowing as inseparable from situated actions in practices. According to Newell (2015: 8):

> "*The epistemology of practice… sees knowledge, or better knowing, as intrinsic to localized situations and practices where people perform or enact activities with a variety of others (both human and non-human) such that acting knowledgeably emerges from this practice and cannot be separated from this practice. Knowledge and practice are thus, immanent; knowledge is not something that stands outside of practice but is rather constantly (re)produced as people and their tools work together with certain consequences (intended or otherwise).*"

Explicit in this definition is the assumption of the epistemology of practice, which claims that 'knowing' is essential for, and inseparable from, all kinds of human activity. In this regard, the issue of 'knowing' is a central concern for most practice-based studies, even if they are not focused on knowledge management (Erden et al. 2014). For those who study knowledge management, such as Hislop (2009) and Newell (2015), a broad categorisation of epistemologies of knowledge based on objectivist and practice views seems to be sufficient, as such distinctions reveal the essential differences in assumptions when it comes to 'knowledge management'. However, for practice-based studies a more nuanced account of practice-based view of 'knowing' is provided by Corradi et al. (2010).

In their study, Corradi et al. (2010) show how the conceptualisations of 'knowing' and 'doing' in practices have historically changed in practice-based studies by differentiating between those that conceptualised practice as an 'empirical object' and those that used practice as 'a way of seeing'. According to Corradi et al. (2010) these two sets of studies are different in the way they analyse the practices. In the first set of studies, which sees the practice as an empirical object, "*the practices (or the process within a practice) become the locus in which scholars study the activities of the practitioners"* (Corradi et al. 2010: 268). The second set of studies, Corradi et al. (2010: 268) argue:

> "*…use implicitly or explicitly, the metaphor of sight: practice as a way of seeing a context, and therefore an epistemology [not only of a distinct kind of knowledge but of anything that can be known]. In fact, many scholars adopt the sight metaphor as a lens for understanding the situatedness of practical reasoning and the contingent nature of organizational rationality*".

A similar distinction is also made by Orlikowski (2002) on how these two different approaches affect the way 'knowing' is conceptualised. For example, Orlikowski (2002) criticises Cook and Brown (1999) who acknowledged the necessity of using epistemology of practice to explain knowledge phenomena, but kept the distinction between 'knowledge' and 'knowing' in their conceptualisation. For Orlikowski (2002), practice and knowledge mutually constitute each other and there is no knowledge that persists beyond the practice. Such a view corresponds to what Corradi et al. (2010) called 'practice as a way of seeing' as 'practice' becomes the only source and outcome for both knowing and action. This gives a definition of 'knowledge' that implies 'knowledgeability' or 'knowing-in-practice' (Orlikowski 2002). In Table 1 below, a number of practice-based conceptualisations of knowing can be found. According to Corradi et al. (2010), the first three conceptualisations correspond to the study of 'practices as empirical objects' and the last four use 'practices as a lens' to explain the phenomena they are studying. In the present study, the terms 'practice-based view', 'practice-based approach', and 'practice-based studies' are used to refer to the studies that Corradi et al. (2010) label as the studies that use 'practice as a lens'.

Label	**Who first introduced it**	**Definition of practice**
Practice-based standpoint	Brown and Duguid (1991)	"*From this practice-based standpoint, we view learning as the bridge between working and innovating*" (Brown and Duguid, 1991: 41). "*For our purposes, then, we intend the term 'practice' to refer to the coordinated activities of individuals and groups in doing their 'real work' as it is informed by a particular organisational or group context. In this sense, we wish to distinguish practice from both behaviour and action. By 'practice', we refer to action informed by meaning drawn from a particular group context*" (Cook and Brown, 1999: 390).
Work-based learning and practice-based learning	Raelin (1997, 2007)	"*This approach recognizes that practitioners in order to be proficient need to bridge the gap between explicit and tacit knowledge and between theory and practice. Work-based learning subscribes to a form of knowing that is context-dependent. Practitioners use theories to frame their understanding of the context but simultaneously incorporate an awareness of the social processes in which organisational activity is embedded*" (Raelin, 1997: 572).
Practice 'as what people do'	Pickering (1990, 1992) Whittington (1996)	"*I sought an understanding of science-as-practice, of science as a way of being in, getting on with, making sense of, and finding out about the world'* (Pickering, 1990: 685). *"The practice perspective is concerned with managerial activity, how managers 'do strategy'"* (Whittington, 1996: 732).

Practice lens and practice oriented research	Orlikowski (2000)	"*A practice lens to examine how people, as they interact with a technology in their ongoing practices, enact structures which shape their emergent and situated use of that technology. Viewing the use of technology as a process of enactment enables a deeper understanding of the constitutive role of social practices in the ongoing use and change of technologies in the workplace*" (Orlikowski, 2000: 404).
Knowing in practice	Gherardi (2000) Orlikowski (2002)	"*Practice is the figure of discourse that allows the processes of knowing at work and in organising to be articulated as historical processes, material and indeterminate"* (Gherardi, 2000: 220–21). "*A perspective on knowing in practice which highlights the essential role of human action in knowing how to get things done in complex organisational work. The perspective suggest that knowing is not a static embedded capability, or stable disposition of actors, but rather an ongoing social accomplishment, constituted and reconstituted as actor engage the world in practice*" (Orlikowski, 2002: 249).
Practice-based perspective	Sole and Edmondson (2002)	"*A practice-based perspective emphasizes the collective, situated and provisional nature of knowledge, in contrast to a rational-cognitive view of knowledge. Practice connotes doing and involves awareness and application of both explicit (language, tools, concepts, roles, procedures) and tacit (rules of thumb, embodied capabilities, shared worldviews) elements. Central to the practice perspective is acknowledgement of the social, historical and structural contexts in which actions take place. Contextual elements are thus seen to shape how individuals learn and how they acquire knowledge and competence*" (Sole and Edmondson, 2002: 18).
Practice-based approaches	Carlile (2002)	"*In a practice-based research approach, it is crucial to be able to observe what people do, what their work is like, and what effort it takes to problem solve their respective combinations of objects and ends*" (Carlile, 2002: 447).

Table 1 - A chronology of practice-based studies (Corradi et al. 2010)

A decontextualised and depersonalised notion of knowledge which assumes that 'knowing' and 'doing' are inseparable, brings different research issues into focus, and enables a different kind of analysis of 'work' and 'organisations' that is valuable for better explaining organisational phenomena (Feldman & Orlikowski 2011; Sandberg & Tsoukas 2011; Gherardi 2012). Gherardi (2008) claims that the promise of practice-based studies to organisational studies is linking the study of working practices to the study of organising through making knowledge an observable phenomenon. A focus on 'doings' rather than propositional categories of knowledge enables this linkage and exposes how organisation is accomplished; and how, or whether, working is different than any other kind of organising. Gherardi (2012: 6) asks, for example, the following questions at the opening of her book:

- What do people do when they work?
- When they work is that all they do?
- How does work differ from non-work?

In response to these questions, Gherardi (2012:7) states that, from a practice-based perspective, "*working is a being-in-the-world tied to the accomplishment of a project through physical activities that are situated in time and space"*. A view of the work as situated activity assumes that working practices are modes of action and knowledge emerging *in situ* from the dynamics of interactions (Gherardi 2006; 2012). This does not reject the possibility of specialist knowledge, however it claims that the division of labour is not a result of possession of distinct sets of knowledge in the minds of individuals, but is rather enacted in the ongoing interactions that take place in work practices. In Gherardi's (2012: 24) words "*all those who [and that] interact within a specific working practice possess different 'pieces' of knowledge which, as in a jigsaw puzzle, must be fitted together to acquire intelligibility".*

Similarly, Sandberg & Tsoukas (2011) claim that the notion of 'intelligibility' (i.e. 'knowledgeability' in Orlikowski 2002) is the key to understanding the 'practical rationality', which is quite different to 'scientific rationality'. Hence, establishing how intelligibility occurs is necessary to understand 'practical rationality', and thus opens up new ways of developing more-practically-relevant theories. Sandberg and Tsoukas (2011) argue that Martin Heidegger's notion of being-in-the-world (Heidegger 1996/1927) provides a valuable point of departure to understand the distinct character of 'practical rationality' that opposes to the 'scientific rationality' (i.e. which is based on the subject–object distinction). According to Heidegger (1996/1927), humans' main mode of being is not based on an internal, subjective mind consciously or sub-consciously understanding an objective, external world, as it is generally assumed by 'scientific rationality' (Sandberg & Tsoukas 2011). Rather, Heidegger (1996/1927) claims that the main mode of being of human is being-in-the-world (Heidegger's 'Dasein'); a world that involves both the individual and external environment as a relational whole. Heidegger's (1996/1927) notion of being-in-the-world implies that it is in this relational whole that both social and material things find their meanings and become '*intelligible'* (i.e. knowledgeable). The concept of practice then becomes the arena that accommodates this relational whole in which contributions of various entities can be studied to establish critical but taken-for-granted, aspects of 'working' and 'organising' without giving priority to any conceptual proposition (Sandberg & Tsoukas 2011).

Various dimensions of ‘knowing-in-practice’ (i.e. enablers of intelligibility) reveal where to look at to understand working and organising. Gherardi (2012: 25) and Nicolini et al. (2003: 21-23) list these dimensions (Table 2), which provide significant insight about how ‘work’ and ‘organising’ could be understood from a practice-based view.

Gherardi (2012: 25)	**Nicolini et al. (2003 : 21-23)**
A pragmatic stance: Practical knowledge is directed to doing, to taking decisions in situations, to solving problems, to maintaining and reproducing… practices [that are recognizable to those who undertake them]	Process-oriented: Knowing is about a world that is always in the making, where ‘doing’, more than ‘being’, is at the centre of attention to signal the constructive nature of the social and material world. The object of inquiry becomes the capacity of humans to perform actions competently, the temporal organisation of such actions, and the resources that makes them possible. Knowledge is about a world in which ‘reality’ is experienced as solid, stable, and certain but in which this condition is an effect, a result, a machination – something that perhaps is but that could have been different. Therefore, the practice-based view favours a vocabulary made of verbs (e.g. organising), and nouns that indicate performativity (e.g. alignment).
An anchoring in discursive practices: Practical knowledge uses the discursive mobilization of cues for action and their positions within a narrative scheme that gives sense to what occurs phenomenologically.	Social: Knowing and mastery are by definition social accomplishments, even when they are attributed to individuals; the adjective ‘social’ points to the localization of learning and knowing not in the mind of the individual but in a social subject, a subject that simultaneously thinks, learns, works, and innovates. Within a practice-based perspective, knowing is always conceived as a social ecology sustained by processes of participation in, enculturation into, and belonging to social patterns like communities, activity systems, and local cultures. People have bodies; they touch, smell, taste; they have sentiments and senses; they argue, yell, fear, get nervous, and even die. They are not solely ephemeral social entities (agents); they are living beings who inhabit a world of life that, far from constituting a ‘problem’, is the object itself of study and representation by this approach.
An anchoring in materiality: Practical knowledge uses fragments of knowledge embedded in objects and technology, and in the material world that interacts with humans and interrogates them	Material: The sociality referred to by practice-based approaches is a sociality not only with other human beings but also with artefacts, both material and symbolic. Artefacts do not play a merely background role. On the contrary, they participate actively in the stories, carry history, embody social relationships, distribute power, and provide points of resistance. Historicity and heterogeneity combine to articulate a world where not everything and everyone is the same, where inequalities and power are continuously produced and reproduced as the pattern of what is doable and sayable, of who can or cannot do or say.

<u>A specific temporality:</u> Practical knowledge emerges from the situation and from situated action	<u>Spatio-temporal:</u> In articulating the 'where' of knowledge, most practice-based approaches refer to its situated nature. The term 'situated' indicates that knowledge and its subjects and objects must be understood as produced together within a temporally, geographically, or relationally situated practice. All practice-based approaches therefore employ a variety of terms that signal not only the locality in time and space of ordering efforts but also their ephemeral, provisional and emergent nature such as 'knowing as performance,' as 'an occurrence,' as 'an event'.
<u>A historical-cultural anchoring:</u> Practical knowledge is also mediated by what has happened in the past and has been learned from experience and in experience. If we consider the setting in which practices are developed, we must include within it both the institutional context and the social system of the division of labour and the rules that regulate social roles.	<u>Contested:</u> Incoherences, inconsistencies, paradoxes, and tensions are all fundamental and ineliminable elements of practices. Breakdowns and 'disturbances' are reflexive learning and fundamental innovation opportunities for the activity system. Disorder, not order, generates meaning. Orders and ordering efforts, knowledge and actions are never complete—they are verbs, not nouns. Ordering and knowing efforts do not coexist in an orderly fashion. Instead, they permanently interfere with each other, resist each other, annul each other in a game of partial connections, of order and disorder that escapes representation and only offers itself through the art of evoking.

Table 2 - Dimensions of 'knowing' in practice-based studies according to Nicolini et al. (2003), and Gherardi (2012)

Although the dimensions of 'knowing' in practice-based studies listed in Table 2 are argued to be common, the body of practice-based studies involve a variety of different theoretical and methodological approaches with varying emphasises on each of them (Schatzki 2001; Stern 2003; Nicolini et al. 2003; Nicolini 2012). Therefore, various practice-based theories and methodologies combine these aspects in different ways to explain how organisational order, stability, meaningfulness, and/or the intelligibility are achieved (or not achieved) through ongoing practices (Schatzki 2001; Rouse 2007; Nicolini 2012; Rivera & Cox 2014). Nevertheless, some scholars have drawn up some shared sensitivities of the theories and methodologies that fall under the umbrella term 'practice-based studies' (Corradi et al. 2010). These are presented in Table 3.

Author (Year)	Shared theoretical sensitivities of practice-based theories and methodologies
Rouse (2007) (Common rationales for theoretical attention to practices)	- To act according to norms and rules is not a 'rule following' activity or a result of any constrictive external power. The norms and rules are enacted in the practices and their power is re-produced in those practices. Rules, norms and concepts get their meaning, and their normative authority and force, from their embodiment in publicly accessible activity. Rules, norms, meanings, conventions or vocabularies are supposed to be grounded in practices, and that grounding makes possible the intelligibility and continuity of society or culture; - Reconciliation of individual (i.e. human) agency and social structure through a view of agency that is grounded on but not totally constrained by a net of interconnected practices; - Emphasis upon bodily agency (i.e. both human and non-human), intentionality, expressiveness, and affective response; - Social agents' understanding of their actions and interactions with others cannot be understood solely in terms of explicitly articulated and accepted propositions or rules. The tacit knowledge and a shared understanding of the language in use contributes to the accomplishment of practices; - A focus on 'micro' interactions does not necessarily reveal an objective reality of the phenomena studied. Practitioners' views are prioritised combined with a reflective assessment of the researcher; - Drawing on the historical and cultural particularity of practices and resisting to any reduction of social context to the thoughts and actions of individual agents by showing how to understand the latter as dependent upon the constitution of meanings that are irreducibly social, without being ontologically mysterious or epistemically inaccessible.
Feldman & Orlikowski (2011) (Some principles of practice theory)	- Situated actions are consequential in the production of social life; - Dualisms are rejected as a way of theorizing; - Relations are mutually constitutive.
Rivera & Cox (2014) (Four core themes of 'practice-based approach' - Gherardi 2009 – excluding Actor Network Theory)	- The productive and reproductive aspect of practices (with a varying emphasis on the stability and change in enacted practices); - Socio-materiality (with different emphasis given to the agency of material, non-human entities); - Relational thinking (1) emphasis on the interconnectedness of a variety of practices that hold practices viable; (2) reconciliation of dichotomies such as agency and structure in practices; (3) historical situatedness of practices to be meaningful; - Knowing and taste (rejection of the positivistic, cognitive and rationalistic views of knowledge along with an appreciation of sensible knowledge).

Table 3 - Shared theoretical sensitivities of practice-based theories and methodologies according to three studies

Consequently, a practice-based approach suggests that all organisational phenomena are produced through the activities performed in practices. Such an approach sees ‘organising’, and therefore ‘order’ as rooted in, and continuously re-produced through ongoing interactions among practitioners and objects (Schatzki, 2001). In this view, structures of organisational life and organisational order don’t have an existence of their own, and can only be identified from a distance, in abstract terms. This is because they are only *patterns* of activities which owe their existence to the repetition of certain ways of acting in practices (Schatzki 2001; Feldman & Orlikowski 2011; Nicolini 2012). Hence, practitioners act in certain ways based on their understandings of the opportunities, possibilities and constraints afforded by the situation. Aggregation of certain ways of acting in practices create patterns that can be identified as organisational structures and order. At the same time, these patterns (i.e. organisational structures and order) are experienced by the practitioners as the ‘context’, and thus, are resources for the practitioners to make sense of unfolding situations, and guide them in their actions and interactions. Therefore, from a practice-based perspective, the practice-level activities and organisational-level order are mutually constitutive, and the local (i.e. practices) and global (i.e. organisations) are inter-connected (Nicolini 2012)

As stated in Chapter 1 - Introduction, a practice-based approach to organisational research can be considered in relation to three ways of studying ‘practice’ (i.e. the empirical phenomena): an empirical orientation on how people act in organisational contexts; a theoretical orientation to understanding relations between the actions people take and the structures of organisational life; and a philosophical orientation to the constitutive role of practices in producing organisational reality (Feldman & Orlikowski 2011). This section introduced these three major orientations of practice-based approach through the concept of ‘knowledge’, or more specifically, ‘knowing-in-practice’/ ‘knowledgeability (i.e. intelligibility) of practice’. It is shown from the literature that a growing interest in ‘knowledge’ in organisation studies in the post-industrial era revealed that ‘knowledge’ is an elusive concept, and is not amenable to categorical organisational analysis. It is further shown that, in this regard, a practice-based view of ‘knowing-in-action’ is an alternative. Implications of the practice-based view in terms of how to study organisational phenomena was presented, thus, establishing the theoretical background of this research. The arguments introduced here are further explored in Chapter 3 – Methodology Chapter, which explains the particularities of the methodological orientation of the present research in a more-detailed way.

2.2.3. The practice-based view of organising interdisciplinary team work

A team is an organisational form which is of particular interest because interdisciplinary design work was organised in teams in the projects studied herein. Consequently, the focus here is on the practice-based studies that aimed to develop arguments regarding how organisation is accomplished in interdisciplinary team work. Considering that the practice-based approach adopted in this research informs not only the theoretical but also methodological rationale, this section also provides an outline of how practice-based research approaches the study of organisation of interdisciplinary team work. Accomplishment of interdisciplinary work is frequently associated with the term 'collaboration' which has a positive connotation about the processes and/or outcomes. However, 'collaboration' is a highly contested construct that has been applied in different fields of research with different meanings (Bedwell et al. 2012). Moreover, from a practice-based perspective, all work is accomplished through 'situated interactions' among human and material entities, and therefore require 'doing together'. Consequently, use of the term 'collaboration' as a generic term is avoided, and the term 'organisation' is the central theme of this section instead.

'Doing together' in the context of interdisciplinary team work has some peculiarities, and therefore deserves to be studied as a distinct type of work. First, Gorman and Sandefur (2011) claim that, although the research in 'the sociology of professions' seems to have been quiescent, the centrality of i) expert knowledge; ii) autonomy; iii) a normative orientation grounded in professional community; and iv) status, income, and other rewards, remain as the central themes in the study of 'knowledge work' which replaced 'sociology of professions'. Differences between various professional disciplines, therefore, are still important social demarcations based on these four factors. Moreover, Oborn and Dawson (2010) make similar arguments about the 'strong social boundaries' between specialists. They further show how the intentions behind building a multidisciplinary team (e.g. innovation), and the established ethos that define its constitution can be significant in the way work is performed in practice.

There are a number of research streams inquiring into the working of teams, such as Team Mental Models (e.g. Lim & Klein 2006), Transactive Memory (e.g. Austin 2003), Group Learning (e.g. Zellmer-Bruhn & Gibson 2006) as well as efforts to establish what 'collective knowledge' is in organisations in general (e.g. Hecker 2012). However, although these studies provide important contributions, they adopt a cognitive view of team performances (Mohammed et al. 2010) rather than studying their 'practical rationality' (Sandberg &

Tsoukas 2011) of organising interdisciplinary team work. Therefore, they are excluded from the present review. Here, the focus is on the previous practice-based studies that are categorised by Erden et al. (2014) as those which study 'practice boundaries and coordination of work' as their central theme: research that studies organisational phenomenon of coordinating work and investigates "*differences and boundaries between social practices that result from the idiosyncratic and situated nature of tacit knowledge, shared understandings, and epistemic cultures that reside in localized practices*" (Erden et al. 2014: 715).

In this section, the literature is presented according to a structure which is based on the dimensions of 'knowing' as summarised in Table 2, placing emphasis on the explanation of i) how a 'pragmatic stance' is expressed; ii) how the spatio-temporal particulars of situations operate; iii) how material aspects are involved; iv) how discursive practices play out; and v) how historical–cultural factors contest or manifest themselves in organising interdisciplinary work practices. From a practice-based perspective, organising work is an ongoing accomplishment achieved through mundane (inter)-actions (Feldman & Orlikowski 2011) which are informed by all five dimensions of 'knowing' summarised in Table 2. Most of the studies that are reviewed in this section reflect either most, or all of these dimensions; however, some of the dimensions might be implicit in their detailed empirical descriptions or analyses. This means that the discussions of practice-based organisational research on interdisciplinary team work generally focus on establishing how one or two of these dimensions of 'knowing' are shaped in relation to others; thus, making one or two of the dimension(s) more explicit and the pivot(s) of the study. Hence, the studies that are reviewed in this section are grouped based upon their pivotal dimension(s) of 'knowing'.

Interdisciplinary 'discursive practices' are foregrounded in most practice-based studies into interdisciplinary work, perhaps because it is the main kind of empirical data that can be reported relatively intact. Some of them establish the discursive background (i.e. what team members talk about when they come together, and how) as case- or situation-descriptions (e.g. Nicolini et al. 2012), whereas some also include quotations from conversations or interviews to show how mundane discursive practices (i.e. trivial looking conversations) contribute to the accomplishment of the interdisciplinary work (e.g. Sole & Edmondson 2002). Therefore, 'discursive practices' are often central to the analysis and explanations in the studies presented in this section either through reported speech, quotations or descriptions of the situations.

However, there only a relatively small number of practice-based studies that primarily focus on the discursive practices, and use them as their pivot to explain the organisational phenomena. In this respect, some studies looked at the formation of interdisciplinary discourses that enabled efficient interdisciplinary communication in team. For example, Majchrzak et al. (2012) suggest that participants of cross-functional meetings preferred practices that minimized members' differences during the problem-solving process. They conclude that these practices helped the team to 'transcend' knowledge differences rather than 'traverse' them as assumed largely in the literature (Majchrzak et al. 2012). Bruns (2013) theorises about the evolution of the discursive practices in team work. She studies multiple scientific cancer research projects over the course of 18 months and develops a 'theory of coordination in collaboration' across domains of expertise, which is mainly based on the sequential routines of the evolution of the discursive practices in interdisciplinary teams (Bruns 2013). According to Bruns (2013), in interdisciplinary team work, in-discipline discourses and interdisciplinary discourses evolve in an integrated way, thus assuring that distinct in-discipline works are synchronised and build upon each other's contributions. Furthermore, Bechky (2006) shows how discursive stereotypes (e.g. role-oriented joking) play a crucial role in the accomplishment of organisation in temporary interdisciplinary teams in the industries characterised by temporary forms of organising (e.g. project-based organising). Moreover, Bechky and Okhuysen (2011) show how interdisciplinary teams that regularly deal with unexpected events as part of their routine work (i.e. a film production crew) depend on the development of an interdisciplinary discourse which enables organisational bricolage, restructuring of activities by role shifting, re-organising routines, and re-assembling the work.

Generally, how the pragmatic stance works out, and how the spatio–temporal particulars of a situation come to pass do not constitute the main points of emphasis in the practice-based organisational studies of interdisciplinary team work. Perhaps this is because they are almost always partly embedded in the detailed descriptions of the case, or are empirical descriptions that are common in most practice-based approaches such as ethnomethodology (Garfinkel 1967) and actor-network theory (Latour 2005). Nevertheless, there are exceptions to this. For example, Suchman (2000) studies a bridge-building project with an emphasis on 'persuasive performances' which highlights how the pragmatism involves not only scientific rationality but also practical exigencies, the desire of engineers to move the project forward, and other stakeholders' perspectives regarding the project. Suchman (2000) states that:

> "*My story about the selection of the 'preferred alternative' [bridge design] should not be heard as an ideal decision process corrupted, but rather as illustrative of the inevitably hybrid, practical, political, technical, contested, negotiated and situationally specific character of organizing a large modern project*" (p. 322).

Another example is the work of Helper et al. (2000) which is based on an extensive fieldwork in the automotive industry where they observed collaborative processes and pragmatic mechanisms along the supply chains. Helper et al. (2000) argue that pragmatism is inherent in all kinds of human sociability and it is a necessity for self-understanding. According to Helper et al. (2000) recognising and investing in pragmatism pays off greatly through the joint discoveries made. They state that their suggestion for a non-standard theory of the firm

> *"…arises from observations of the inherent sociability of human behavior and the development of reciprocity norms between and among individuals and groups. Its central theme is the ambiguity and provisional nature of all understanding, from the simplest verbal exchange to the most complex co-development project. As a consequence, interlocutors and partners must cooperate in pursuit of mutual intelligibility as a condition for self-understanding. In this view, because of the mutual vulnerability resulting from their ignorance of the world, humans are by nature at least as disposed to be cooperative in order to learn as to be guileful. Once the cooperative exploration of ambiguity begins, the returns to the partners from further joint discoveries are so great that it pays to keep cooperating*" (Helper et al. 2000: 444-445).

The idea of 'pragmatic collaboration' is acknowledged in further practice-based studies (e.g. Jarzabkowski et al. 2013), and was also employed in the design in construction research in order to explore the pragmatics of inter-organisational knowledge creation using interoperable information technologies (Berente et al. 2010). Another important concept that emphasises the pragmatic nature of knowing-in-practice is the concept of 'boundary object' (Star 1988; Star and Griesemer 1989). Although the pragmatic stance of the concept of 'boundary object' is rarely acknowledged in the studies that use it (Star 2010), the originator of the concept explains the logic behind the development of the concept as follows:

> *"Consensus was rarely reached, and fragile when it was, but cooperation continued, often unproblematically. How might this be explained?"* (Star 2010: 604).

Star (2010: 602) claims that the concept of boundary object involves not only an object in itself but "*a sort of arrangement*", "*an organic infrastructure*" that allows different groups to work together without consensus by satisfying multiple information and work requirements. Thus, she shows how the concept explains the way in which pragmatic stance works out in practice that involves multiple information and work requirements. Some studies that used the concept of 'boundary object' mainly with a focus the material properties of the object are presented later in this section.

Among the studies that mainly emphasise the situated spatio-temporality of the knowing-in-practice, Sole and Edmondson's (2002) work is of particular interest as it studies geographically dispersed, multi-site, new product/process development projects. In their study, Sole and Edmondson (2002) show the significance of the physical locations and the sense of temporality held in each site in shaping the way practices unfold. They show, for example, how a sense of urgency emerged through unexpected client requests, and merged with the knowledge about the various production processes going on at the physical site, and thus, enabled meeting a strict delivery deadline for a new product under development (Sole & Edmondson 2002). Another interesting example is Scarbrough et al.'s (2004) work on project-based learning in construction projects. They show how co-location and new contractual arrangements in a project shift temporal boundaries, and result in reducing learning boundaries in the project by providing important incentives for the development of learning through new shared practices. Assuming a 'nested' view of learning (i.e. learning occurs at several different but interrelated levels at the same time), they provide explanations about the relation between intra-project, inter-project and intra-organisational learning based on the spatio-temporal particularities of the project practices.

Putting emphasis on the role of materials or objects in explaining the accomplishment of the interdisciplinary work is one of the most commonly employed approaches in the literature. This generally involves showing how the inherent materiality of various specialist practices conflicts and/or is aligned through certain objects that are jointly used as well as the interdisciplinary discursive practices that accompany these conflicts and/or alignments. The concept of 'boundary object' has been frequently used to explain the role of jointly used objects in the accomplishment of interdisciplinary work. "*Boundary objects are flexible epistemic artifacts*" (Bechky 2003: 326), "*that inhabit several intersecting social worlds and satisfy the information requirements of each of them*" (Star & Griesemer 1989: 393). Carlile (2002) provides a typology of boundary objects based on the type of the boundaries (i.e. syntactic, semantic, pragmatic) work through. In a similar line of thought, Bechky (2003) shows how the usefulness of the boundary objects depend on their ability of tying together adequate elements of the specialist work contexts. Bechky (2003) further argues that boundary objects can also have effects on ordering in interdisciplinary work, as they do not merely allow knowledge sharing through traversing knowledge boundaries, but also carry other social and political aspects of the practices they connect. In a similar line of thought, Barley et al. (2012) argue that the meanings of boundary objects are not established in interdisciplinary actions, and meanings can be strategically inscribed in them to drive certain courses of action in remote practices as part of interdisciplinary work. Franco (2013), drawing on Carlile (2002; 2004), conceptualises models as boundary objects to better understand the type of model-supported problem-solving collaborations, and claims that models can 'transfer' at syntactic boundaries, 'translate' at semantic boundaries, and 'transform' at pragmatic boundaries to support interdisciplinary work. Nicolini et al. (2012) study the role of objects in interdisciplinary team work through the data they collected from a bioreactor development project. They differentiate between the main functions of a variety of objects used in interdisciplinary work, and categorise them as epistemic/activity objects (i.e. 'primary objects of collaboration'); boundary objects (i.e. 'secondary objects of collaboration'); and infrastructure (i.e. 'tertiary objects of collaboration').

Finally, there are also practice-based studies that foreground the effects and/or alignment of multiple historical and cultural anchorings in interdisciplinary work. Hibbert and Huxham (2010) develop a theory of the 'role of tradition in collaboration' based on their empirical data from three different situations of interdisciplinary team work. In a similar line of thought, Anon (2004) – The Special Issue on Project-Based Organizations, Embeddedness and Repositories of Knowledge – involves a number of practice-based studies that explore the historical and cultural enablers of interdisciplinary project-based working. Similarly, Bechky (2006) shows how interdisciplinary temporary organisations are "*organised around structural role systems whose nuances are negotiated in situ* (Bechky 2006: 3). There are also studies that look at how a multiplicity of institutions evolve through or play out in practical interactions of interdisciplinary work. For example, Lawrence et al. (2002: 281) argue that "*collaboration can act as a source of change in institutional fields through the generation of 'proto-institutions': new practices, rules, and technologies that transcend a particular collaborative relationship and may become new institutions if they diffuse sufficiently"*. Helfen and Sydow (2013) study inter-organisational negotiation processes. They conclude that "*three types of (proto-)institutional outcomes produced by these processes: institutional creation, modification and stagnation*" (Helfen & Sydow 2013: 1073). In Delbridge and

Edwards (2013), a case vignette of the design-and-build of luxury yachts is used to represent the struggles of practice to refine existing explanations of how actors inhabit complex institutional settings.

The studies presented in this section show that the practice-based approach is fruitful and provides nuanced understandings of how interdisciplinary team work is accomplished. As the studies outlined in this section show, knowledgeability of interdisciplinary practices can be traced through discursive, spatio-temporal, pragmatic, cultural-historical and material aspects of practices, and their unique interrelations. Indeed, perhaps the most significant contributions of the listed studies are the ways they relate these dimensions to each other through detailed analyses of otherwise non-significant, mundane aspects of practices. For example, Bechky (2006) shows how interdisciplinary discourses can be institutionalised in industries characterised by interdisciplinary team work, thus, enabling rapid accomplishment of organising in temporary interdisciplinary teams. Other examples are the works that use the concept of 'boundary object' to interrelate the material aspects of interdisciplinary practices with pragmatism (e.g. Star 2010), or with in-discipline and interdisciplinary discourses (e.g. Star & Griesemer 1989).

Other practice-based studies have developed higher-level concepts that encompass and inter-relate several dimensions of 'knowing'. These include, for example, 'Communities of Practice' (Wenger 1998) which provides a detailed explanation of how discursive, historical-cultural, and material dimensions of knowing-in-practice are mutually constitutive; 'Genre Systems' (Yates & Orlikowski 2002) which provides an explanation of how spatio-temporal, discursive and material aspects of interdisciplinary practices are intimately related; and 'Trading Zone' (Kellogg et al. 2006) which presents an account of the interrelations between the pragmatic, discursive, material and spatio-temporal aspects of 'knowing' in interdisciplinary practices. Consequently, the literature presented in this section reveals that a practice-based examination of technology-fuelled change needs to consider both the trivial, and non-trivial shifts in all dimensions of 'knowing' listed in Table 2, as well as their changing interrelations in accomplishing interdisciplinary team work.

2.3. Theorising Design, and Organising Design in Construction

This section begins by focusing on various theorisations of the nature of design, and corresponding views of design process in a chronological order (Section 2.3.1). Although the account of evolution of the ideas presented in Section 2.3.1 is not exhaustive, the section aims to reveal the interdependencies among some of the major debates in the field.

Therefore, Section 2.3.1 provides a general understanding of the problematic nature of the construct of 'design' before focusing on interdisciplinary design in construction.

In Section 2.3.2, the focus shifts to organising and managing design in construction. Section 2.3.2 introduces the major debates in interdisciplinary design work and the different approaches adopted to explore it. In this respect, Sections 2.3.2.1 and 2.3.2.2 review two sets of literature that are grouped under the headings of 'design management in construction' and 'design collaboration in construction' respectively. These reviews reveal that research on organising design in construction is dispersed, non-accumulative, and confused in terms of its concepts (e.g. collaboration) and theoretical directions. In Section 2.3.2.3, a particular attention is given to the studies that focus on the active role of design artefacts in organisation of interdisciplinary design work. This is because accounting for the materiality of practices is essential for a practice-based approach, and the design artefacts are the hallmark of the materiality of the interdisciplinary design projects in construction.

2.3.1. Theoretical views on design

The 1950s and 1960s were marked by the questioning of the possibilities, conditions and limits of universal (scientific) rationality (e.g. Simon 1957; Kuhn 1970). Minneman (1991) argues that the design research appeared as a specific topic of research in 1950s due to the increasing complexity of the designed artefacts and the doubts about whether increasingly complex engineering projects would remain manageable. In the relatively young field of design research, several viewpoints emerged from this debate around rationalism. These different viewpoints provided alternative explanations of what design was, what could be designed and how, and what the role of designer could be. For example, Alexander (1964) claims that the ultimate object of design is 'form' and the designers must employ rationality in tackling the design problems, yet they need to distinguish between the intuition, and mathematics and formal logic in their designing. Simon (1999/1969) in his famous book 'The Sciences of the Artificial' differentiates between the 'natural' and 'artificial' phenomena on the basis of their relation with their environment. Simon (1999/1969: xi) states that:

> *"If natural phenomena have an air of 'necessity' about them in their subservience to natural law, artificial phenomena have an air of 'contingency' in their malleability by environment."*

According to Simon (1999/1969) this points out a fundamental difference between the natural and the artificial which is based on the limits of rationality. He claims that:

"… *the empirical content of the phenomena, the necessity that rises above the contingencies, stems from the inabilities of the behavioural system to adapt perfectly to its environment – from the limits of rationality*" (Simon 1999/1969: xii).

Building upon this differentiation, he deduces that any endeavour based on the assumption of 'rational behaviour' (e.g. thinking, problem solving, learning) does not account for the limits of rationality, and this is the main difficulty in human endeavours around 'the artificial'. It is in this space between the human endeavour within the limits of rationality and the empirical reality that Simon (1999/1969) positions 'the sciences of the artificial', or design:

"*… I thought I began to see in the problem of artificiality an explanation of the difficulty that has been experienced in filling engineering and other professions with empirical and theoretical substance distinct from the substance of their supporting sciences. Engineering, medicine, business, architecture, and painting are concerned not with the necessary but with the contingent – not with how things are but with how they might be – in short, with design. The possibility of creating a science or sciences of design is exactly as great as the possibility of creating any science of the artificial. The two possibilities stand or fall together*" (Simon 1999/1969: xii)

In this conceptualisation, "*the object of the science of the artificial is not out there to be discovered but to be designed"* (Yoo 2012: 135) with bounded human rationality (Simon 1957). While Alexander's (1964) proposition to deal with the increasing complexity that design must face is using a skilful combination of both rationality and intuition, Simon (1999/1969) favours rationality, which recognises its own limits to tackle complexity (for example, Simon (1999/1969) extensively covered 'optimisation theory' in his book).

Rationalistic approaches to the process of designing have attracted criticism. One of the most known critiques at that time came from Rittel and Webber (1973) who claimed that the design process, and any other professional endeavour, cannot be entirely captured through the formulations around goal setting, complexity modelling, constraints and rules, and state–space search (Coyne 2005). According to Rittel and Webber (1973) two kinds of problems can be distinguished to meaningfully discuss the suitable method to approach them. First, there are 'tame' problems that are suitable to be understood and resolved in certain pre-agreed terms such as problems in the natural sciences, which are definable and separable and may have solutions that are findable. Second, there are 'ill-defined' or 'wicked' problems for which there are no definitive formulation, and "*the information* *needed to understand the problem depends upon one's idea for solving it*" (Rittel & Weber 1973: 161). As they put it:

> *"The formulation of a wicked problem is the problem! The process of formulating the problem and of conceiving a solution (or re-solution) are identical, since every specification of the problem is a specification of the direction in which a treatment is considered"* (Rittel & Weber 1973: 161)

According to Rittel and Webber (1973), the 'wicked problems' are quite different than the 'tame' problems also in the sense that the evaluation of the solutions of the wicked problems are not based on true or false statements (but on concepts of 'good' or 'bad'); and investigation and resolution of wicked problems are not marked with clearly defined logical events, but pragmatically, within the confines of the limitations external to the problem such as time, money and patience (Rittel & Webber 1973).

Despite the criticisms of the rationalistic approach to design, according to Dorst and Dijkhuis (1995), the early 1960s were marked as hosting the 'first generation' methods of design methodology which were highly positivistic in their nature because of the influences from theories of technical systems. Nevertheless, according to Coyne (2005) and Kimbell (2011), the criticisms around the rationalistic view of design gave birth to a 'second generation' of analytical methods that focused on what designers do and how they think (Kimbell 2011). Coyne (2005) states that this move shifts the ground to an empirical consideration of how professional rationality is established, giving a profession a unique character and a texture that can be recognized externally in rejection of a rationality based on an abstract logic (Coyne 2005). One of the most recognised works in this so called 'second generation' of analytical methods, is the work of Schön (1983). In contrast to a rationalistic view of design process, Schön (1983) argues that problems are not given in professional practices (as it was assumed in professional education), and therefore professional practices must not be seen as problem-solving exercises. He argues that professional practice of individuals can be described as a process of 'reflection-in-action', in which practitioners 'frame' problems based on their judgements (Schön 1983). According to Schön (1983), these judgements, which he calls 'professional artistry', enable professionals to tackle unique problems in practice. Based upon this line of thinking, he claims that design is a 'reflective conversation with the situation' which involves reflectively acting on the situation to 'frame' the problem, and advancing the perception of the problem (Schön 1983). The core differences between the rationalistic, problem-solving view of design process and the reflection-in-action view of it are summarised by Dorst and Dijkhuis's (1995) (see Figure 2).

Although Schön's (1983) view of designing is a big leap from the rationalistic view (as can be seen in Figure 2), there are also similarities. In Schön's work there is emphasis in most aspects of the dynamism inherent in practices such as his emphasis on unfolding process, action, temporal situatedness, materials that the designers interact with, sensible knowledge etc. (e.g. Schön 1983; 1984; 1988; Schön & Wiggins 1992), that makes his position very different than the rationalistic one. Nevertheless, Schön's explanations also emphasise the individual designer who possess 'frames' (e.g. Schön 1984) or 'design knowledge' which can be compartmentalised (Schön 1988). Hence, Schön's view of designing is individualistic and cognitivist in its own way. Therefore, in these terms, it has similarities with the rationalistic view of designing.

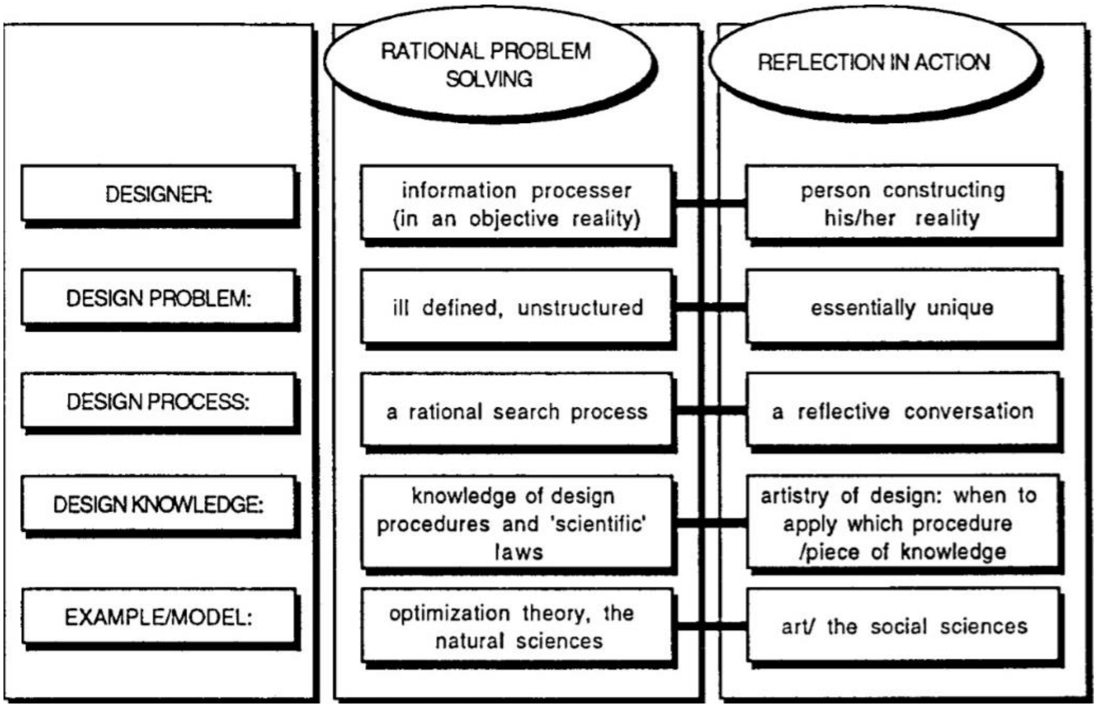

Figure 2 - The 'rational problem solving' and the 'reflection-in-action' paradigms (Dorst & Dijkhuis 1995)

Some other streams of design research shift the focus away from individual, to historically-situated social processes among designers, and emphasise the socially constructed nature of design rather than framing the process based on individual or distributed (group) cognition. For example, Minneman (1991), in his work named 'The social construction of a technical reality', explores the ways that design emerges from interactions among individuals and groups as they establish, maintain, and develop a shared understanding. Bucciarelli (1994) conducts an ethnographic study involving three engineering projects and witnesses the everyday world of engineering. In doing so, he reveals that the engineering design is not an instrumental process but a historically situated social process that is full of uncertainty and ambiguity (Bucciarelli 1994).

Nevertheless, there are also studies that appreciate group dynamics in the process of design through adopting cognitivist or individualist approaches. For example, Valkenburg and Dorst (1998) study the reflective practice of design teams, based on the theory of design process developed by Schön (1983). A more radical cognitivist, but not individualist, approach is based on the concept of 'distributed cognition' (Hutchins 1990). The perspective of distributed cognition claims that it is a culturally constituted functional group rather than an individual mind that accomplishes tasks. In this view, information is propagated through a system as representational states of mediating structures (Hutchins 2001). According to Hutchins (2001) interactions among the human and non-human entities of such groups can be understood in terms of information flow in order to provide descriptions about the cognitive processes that enable performances both at individual and group levels. Busby (2001), for example, analyses the errors made in the design of a complex industrial plant, and states that there were 75 cases of failure of distributed cognition. Le Dantec (2010) studies two architectural meetings and claims that "*as the three individuals worked to refine the design and participate in its development, the external media of the site plan, the tools of calculation like the architect's scale, and the act of sketching and gesturing developed as a complex system of cognition*" (Le Dantec 2010: 73).

More recently, another debate that has attracted increasing attention in design research concerns the notion of 'design thinking' (e.g. Buchanan 1992; Kimbell 2011; Dorst 2011). The debate considers questions about the nature of design because of the ambition of applying 'design thinking' to the areas that are traditionally considered out of the realm of design; as Kimbell (2011: 289) puts it:

> *"…[people] have trouble articulating what it [design thinking] is, whether all designers can do it, whether it is something new or just a different name for what good designers have always done, and why it might be a good thing that non-designers can learn it and do it too – or perhaps they do it already. Decoupled from any one field or discipline of design, design thinking is meant to encompass everything good about designerly practices".*

This line of questioning can be traced back to 1970s. Jones (1970), in his book called ‘Design Methods’, shows how rationality and intuition can co-exist but does this in a different way to Alexander (1964) and Simon (1999/1969). Alexander (1964) advocates the use of rationality together with intuition, but, in his work, the designer is someone who is privileged and the arguments are made from the designer’s point of view. Simon (1999/1969) recognizes the limits of rationality but looks for rational ways that can eliminate the negative effects of bounded rationality by developing his arguments about the design output: the artificial. On the other hand, Jones (1970) also argues for co-existence of intuition and rationality but focuses on the design methods. While all three studies consider both the nature and process of design, their positions differ in terms of their starting points, which are the designer, the design product, and the design process. Therefore, the stream of research that takes its starting point as the design methods (e.g. Jones 1970), or in other words, ‘designerly problem formulation and solving’ (Cross 1982), focus on the problems of defining what a designer is, and what can be designed. This leads to the question of whether ‘design’ is a skill that can be applied to all aspects of the world by everyone.

Cross (1982), for example, claims that there are designerly ways of knowing in addition to scientific and artistic ways of knowing. In his conceptualisation, design is somewhere in between these two ways of knowing and bridges them, and thus is strongly associated with the ‘technology’ which connects scientific and artistic ways of knowing. Cross (1982) argues that designerly ways of knowing can be distilled to a set of aspects of design activity which should make the core of *design* a discipline in its own right, and not a scientific nor an artistic one. He also argues for the inclusion of design education in general education, to equip all students with designerly ways of knowing to enable their ability to make connections between the scientific and artistic cultures (Cross 1982). Buchanan (1992), on the other hand, provides a slightly different view of design thinking, leaning towards pragmatism (Dewey 1960/1929). Instead of positioning the role of designing between technical and artistic, Buchanan (1992) positions it between theoretical knowledge and practical actions, implying that the practices people deal with are about unity rather than fragmentation (which characterise modern theoretical scientific knowledge). Buchanan (1992) argues that the continuous advances in fragmented areas of theoretical knowledge:

> “…*flourish[es] as specialized studies, leading to the perception of an ever more rich and detailed array of facts and values. Although these subjects contribute to the advance of knowledge, they also contribute to its fragmentation, as they have become progressively narrow in scope, more numerous, and have lost ‘connection*

> *with each other and with the common problems and matters of daily life from which they select aspects for precise methodological analysis.' The search for new integrative disciplines to complement the arts and sciences has become one of the central themes of intellectual and practical life in the twentieth century. Without integrative disciplines of understanding, communication, and action, there is little hope of sensibly extending knowledge beyond the library or laboratory in order to serve the purpose of enriching human life"* (Buchanan 1992: 6)

Buchanan (1992) continues by defining design as a 'liberal art of technological culture' in which different specialisms increasingly produce and rely on their technologies but are far from integrating them for new productive purposes.

> *"The significance of seeking a scientific basis for design… rather… lies in a concern to connect and integrate useful knowledge from the arts and sciences alike, but in ways that are suited to the problems and purposes of the present. Designers, are exploring concrete integrations of knowledge that will combine theory with practice for new productive purposes, and this is the reason why we turn to design thinking for insight into the new liberal arts of technological culture*" (Buchanan 1992: 6).

In this regard, according to Buchanan (1992), design problems are 'wicked' because design has no special subject matter of its own apart from what a designer conceives it to be, and design thinking can be applied to any area of human experience. Buchanan (1992) argues that in this view of design thinking, what matters then is the 'integrative argument' that needs to be developed by the designer to synthesise i) the ideas of designers and manufacturers about their products; ii) the internal operational logic of products; and iii) the desire and ability of human beings to use products in everyday life in ways that reflect personal and social values. Dalsgaard (2014) further advances the role of pragmatism in design thinking and shows how pragmatist concepts can be employed to guide and inform specific design cases.

Nevertheless, a counter, or perhaps complementary, argument to a universally applicable design thinking comes from those who adopt culturally or practically embedded perspectives to study design. For example, Julier (2006) argues for studying design as a culture that is open to the effects of the immediate context of designing, but also shaped by pervasive norms, artefacts, organisational patterns, and morality which enable universal applicability of design to a variety of unique issues. Furthermore, Le Dantec (2010) shows how social, cultural and spatio-temporal aspects determine the practice of the design meetings.

Another approach that considers the cultural and historical embeddedness of design is the practice-based view of design. Nevertheless, different than design-as-culture (Julier 2006), the view that sees design-as-practice (Kimbell 2009) puts an emphasis on the interactions of practitioners (with human and non-human entities) which take place in historically, socially and culturally situated practices (Kimbell 2011). Earlier works of Bucciarelli (1994) and Minneman (1991) provide detailed descriptions of the ways that designers go about their work, and the artefacts they engage with in situated, embodied and historically embedded practices. Nevertheless, a focus on practice, which sees the practice as the field of inquiry, has only recently started to attract more attention (e.g. Tonkinwise 2011; Luck 2012a). Harty (2008) shows how an attempt to change the traditional design artefacts that were previously central to design projects faces numerous challenges due to the corresponding changes that are needed both in local and interdisciplinary practices. Furthermore, Harty and Whyte (2009) claim that a change in the traditional design artefacts in interdisciplinary construction design projects result in 'hybrid practices' which include aspects of both previous and anticipated practices, rather than a sudden wholesale shift to novel anticipated practices. Whyte et al. (2007) show how visual materials are treated both as fixed and open, suggesting that patterns of using visual materials in practice are important in the interplay between the discursive practices, the types of visual materials in the evolution of knowledge, and in structuring social relations for delivery. Murphy (2012) provides a practice-based account of designing by showing how in practice "*particular gesture forms are repeatedly and consistently linked to particular concepts, which in turn are translated into hand sketches and computer drawings, which are then used to create a prototype ready for show*" (Murphy 2012: 1966). Thus, he shows the mutual enactment of human interactions and documented design. Luck (2012a) states that in studying how the 'design work' is done in practice:

> *"… it is not 'thinking' as a mental process that is witnessable in a sequence of actions, but what it is that a sequence of actions accomplishes (without assuming insight into thought processes, or interpretation of the motive behind an action) … [what presented in this kind of studies] are accounts of the lived-work that are intrinsic to the doing of design*" (Luck 2012a: 525).

According to Kimbell (2009) 'design-as-practice' can provide a critical understanding of design at least in four ways. First, it can help to avoid the cognitivist view by emphasising a logic of practice enacted in a situation. This would therefore produce explanations of how knowledge that is required to act in design practices becomes formalised, routinised, and how institutions take shape in and through practices. Second, it can provide explanations about the complex connections between design artefacts and those who undertake the design work. Third, it can enable a better understanding of the role of end-users and peripheral stakeholders in the practice of design. Fourth, it can provide an account of how designers and stakeholders involved in design thinking, what they do and how it feels (Kimbell 2009).

Finally, another way of understanding design activity is offered by Yoo (2012; 2013) based upon the technological advancements in information and communication technologies (ICT) and their pervasiveness in all aspects of life. Yoo (2012; 2013) analyses the 'generativity' of the ICT data that can travel along a large variety of technological systems and become part of a variety of various design endeavours. According to Yoo (2012; 2013) it is not only the mobility of the data that radically changes the design situations, but the capacity of ICT to automatically combine a variety of data beyond the knowledge of the originators of the data. In this respect, Yoo (2013) argues that, increasing reliance on digital media for all sorts of activity, and the 'generativity' of technologically interoperable data, change the previously established relations between designer, design product and the process of design. Yoo (2012) claims that the distinction made by Simon (1999/1969) about 'natural' and 'artificial' does not hold anymore, because once an artefact is designed, its design does not stop; it evolves over the time "*often beyond the intent and imagination of the original designers*" (Yoo 2012: 135). These ideas have similarities with some of the information systems design studies that claim that ICT artefacts should be designed in a way that considers 'secondary design' in their practical use (Germonprez 2011). Nevertheless, Yoo's (2012; 2013) claims involve a different edge by emphasising the 'generativity' (Eck et al. 2015) of interoperable data and its effects on the way design should be conceived.

2.3.2. Organising design in construction

The previous section has showed that the research on the nature and process of design is fragmented and divergent both philosophically and methodologically. What can be designed, who is entitled to design, and how the design process works, have all been central issues of ongoing debates. It has been also shown from the literature that societal changes, such as widely-adopted technological advances, have resulted in shifts in the historically established positions in these debates as well as triggering new positions. Perhaps, then, the logical first step in reviewing the literature on organising design in construction is to establish how design has been theorised in the context of construction industry. All studies that explore construction activity and organisation at industrial scale -and there have been relatively few- emphasise the distinctiveness of the construction industry (e.g. Koskela 2000; Koskela et al. 2002; Dubois & Gadde 2002; Winch 2003; Boyd & Chinyio 2006; Fernández-Solís 2008; Morton 2008); thus, further justifying the need for first discussing the unique nature of design in construction before moving on to the more specific literature on organising design in construction.

However, there are surprisingly few studies that aim to build theory about the unique nature of design in the construction industry (Koskela et al. 2002; Bröchner 2009; Zerjav 2012; Baudains et al. 2014), and these contributions do not converge into wider theories. Additionally, the research on organising and managing design in construction is largely dispersed, non-accumulative, and confused in terms of concepts and theoretical direction. Consequently, it is difficult to establish theoretical and conceptual ground(s) when studying design in construction. Two reasons for this shortcoming could be invoked.

First is the theoretical and conceptual confusion in the wider field of construction management research, in which several theoretical perspectives are employed without raising the adequate awareness, thus, rendering higher level paradigmatic discussions impossible (Bygballe et al. 2013). For example, Bygballe et al. (2013) identify four different theoretical models that are assumed in the construction literature to explain how organisations act in relation to each other. They conclude that there is a need for increased awareness of the utilisation of these models which consider different units of analysis (i.e. transactions; projects; supply chains; networks), and therefore provide different explanations about the organisational phenomena in construction in general, and the nature of design in particular (Bygballe et al. 2013).

Second is the different value creation logics, which can be in tension with each other, applied by various professional disciplines that are part of the construction industry (Bygballe & Jahre 2009). This implies that there are differences among the perceptions of the nature of design of various practitioners in the construction industry. The idea that design in construction means different things to different design practitioners operating in the industry is in line with Ho (2011) who claims that the work in construction ethics is very limited while specific professions in construction design have their own streams of research, such as architecture (e.g. Wasserman et al. 2000) and structural engineering (e.g. Roddis

1993). Similarly, Zerjav (2012) draws on Lawson (2005), Ankrah and Langford (2005) and Vermaas and Kroes (2007); and claims that:

> "*… urban planning and architectural design are defined as planning activities with a broad impact on not just physical world as we know it, but also on the society that comprises it. On the other hand, however, engineering has been reduced to a technical support role, outside the realm of creative design… On the one hand, engineering implies a scientific mental model based on analysis, whereas design implies the constructive and creative mental model based on synthesis"* (Zerjav 2012: 42).

However, although Zerjav (2012) acknowledges the presence of different perceptions of the nature of design, he nevertheless claims that this should not be a reason to give up on developing an encompassing view that better captures the practice of designing in construction in which various practitioners continuously engage with each other.

> "*Within the existing domain-dependent design concepts, architectural designers are perceived more in terms of artistic creativity, while engineering designers are in their mental programs more aligned with hard-sciences approach. Although this conclusion is hardly debatable, it also clarifies such claims are based on an implicit assumption that architects are artists and engineers are hard-core scientists. Although many would agree with this claim, the term of design and engineering is far from reality as both architecture and engineering engage [together] in design activity"* (Zerjav 2012: 45).

In addition to the differences among design disciplines in construction, as reported by Ankrah and Langford (2005), there is also disconnection between design and construction phases, or more specifically between the cultures and orientations of designers and contractors, which implies further complications for building inclusive and comprehensive theory on design in construction. Overall, these provide theoretical support for Andersen et al. (2005) who claim that design management in construction can be conceptualised in three different ways: i) design management as 'integrators of design and construction'; ii) design management as 'managers'; and iii) design management as 'meta designers' (incorporating others such as stakeholders, consultancies and sub-contractors as co-developers or co-designers; in summary taking the larger whole into account).

The differing values, cultures, and processes of those organisations that are involved in construction projects are generally articulated as 'fragmentation' both between the design and construction phases of construction projects, and between different professional disciplines that are involved in design (e.g. Nitithamyong & Skibniewski 2004; Baiden et al. 2006; Elmualim & Gilder 2014). Moreover, this so-called 'fragmentation' is generally associated with claims that the construction industry is not efficient or productive enough (e.g. Latham 1994; Egan 1998; Nitithamyong & Skibniewski 2004); and thus, it is assumed to be the central problem that needs to be tackled in organising or managing design in construction (e.g. Kent & Becerik-Gerber 2010; Elmualim & Gilder 2014). 'Integration' has appeared as the remedy in this debate (e.g. Love et al. 2004; Oh et al. 2015; see also Anon 2010). A large number and variety of studies in the literature are mostly preoccupied with this 'fragmentation-integration' debate, taking it for granted and as their starting point, without necessarily engaging with a conceptual analysis of 'fragmentation' or 'integration' (e.g. Kagioglou et al. 2000; Love et al. 2004; Oh et al. 2015). This means that they generally either interpret the empirical findings from interdisciplinary design in construction as a process of 'integrating' autonomous actors/entities, or conjecture about how design could be improved based on the pre-assumed structural challenges originating from 'fragmentation'. However, as shown by Baiden et al. (2006), the arguments of 'fragmentation' and 'integration' in research in construction must be subject to critical examination because the extent and characteristics of the required 'integration' to tackle the so-called 'fragmentation' are elusive, and involve joint consideration of several interdependent dimensions (i.e. social, economic, technological, and so on).

Research that are concerned with organising and managing (interdisciplinary) design in construction, and thus dealing with fragmentation-integration debate, can be grouped under the headings of 'design management' and 'collaboration in design' in construction. Therefore, studies around these two topics are reviewed in Sections 2.3.2.1 and 2.3.2.2 respectively. It will be evident from the overviews that both areas of research are difficult to navigate and/or combine since there are no agreements around what 'design management' and 'collaboration in design' mean or involve, and hence, concepts are interchangeably used in a variety of studies that employ different research approaches and foci. Following this, in the last sub-section, Section 2.3.2.3, studies that explore the roles of design artefacts in organisation of interdisciplinary design work are summarised. This is because consideration of the materiality of practices is essential for practice-based studies, and the design artefacts are the hallmark of the materiality in interdisciplinary design practices in construction.

2.3.2.1. Design management in construction

The concept of 'construction design management' is relatively new to the construction industry (Emmitt 2016). According to Emmitt (2016) the literature on design management in construction started to attract attention in the 1990s, and therefore it is sparse and tends to be mostly associated with architecture. Therefore, Emmitt (2016) argues that construction design management is an innovative role which is different than traditional approach to management of design in construction by professionals from different design disciplines who are mainly concerned about their parts of design. However, in contrast to the encompassing view of design management of Emmitt (2016), design management literature still largely adopts a view of design which is based on differentiation between various disciplines (e.g. different design consultants and contractor) and phases (e.g. pre-construction and construction) (e.g. Tzortzopoulos & Cooper 2007; Eynon 2013; Emmitt & Ruikar 2013), thus, resonating with the traditional 'fragmentation-integration' debate. Both Zerjav (2012) and Emmitt (2016) argue that the most-recent developments in the field of design management revolve around some high-level concepts which are used as pivotal points such as Building Information Modelling (BIM) (e.g. Elmualim & Gilder 2014) and sustainability (e.g. Novak 2014). This aligns with the 'fragmentation-integration' debate in that it implies that an overarching explanation of design in construction, which transcends the differences between various design disciplines, is lacking; and it is only through the overarching constructs, such as 'BIM' and 'sustainability', that design in construction can be thought as a whole (i.e. that can be understood beyond the differences between various design disciplines).

Similarly, also the management approaches considered in the design management literature have been criticised for being unsuitable to capture the design in construction as a whole. For example, Zerjav (2012) reviews the design management methodology, and argues that there is a need for interpretative approaches to design management because all the available methodologies adopt a rationalistic view of design, and therefore, rely on "*classical project management based on analytical reductionism*" (Zerjav 2012: 53). This aligns with Emmitt's (2016) argument that early work on construction design management (e.g. Gray and Hughes 2001) sees design management as a sub-set of project management. Koskela et al. (2002) are also sceptical about over-relying on classical project management tools to manage design in construction, and conclude that theory-driven tools and methods are needed to improve the management performance in construction design.

Further, Zerjav (2012) and Zerjav et al. (2013) argue that currently the everyday undertaking of design is mainly researched and understood through interpretivist approaches, whereas the management of design organisation is understood through rationalistic (i.e. classic project management) approaches, thus, resulting in a knowledge (and practical) gap that needs to be bridged. Zerjav et al. (2013) use Schön's (1983) concept of 'framing' to bridge this gap between the practical performance and management of design in construction. They argue that "*the existence of frames in the design activity gives context to managerial decision making in steering the design process*" (p. 130), thus, establishing the notion of 'managerial decision-making frames' (Zerjav et al. 2013). Similarly, recently, research on design management has started to study design management as organisational management, which also enables bridging the gap between the practice of designing and the management of design. For example, the concepts of 'interdependencies' (Bølviken et al. 2010), 'organisational power' (Knotten et al. 2015), and 'design boundary dynamics' among the organisations involved in the design (Zerjav 2015) are used to explain design practices as well as to produce arguments for their management. These efforts enable critical perspectives on the traditional fragmentation-integration debate by considering design in construction as a dynamic relational whole.

2.3.2.2. Design collaboration in construction

The studies that are grouped here under the umbrella term of 'design collaboration in construction' also deal mainly with the 'fragmentation-integration' debate. The present research avoids the use of the term 'collaboration' as a generic term in its analyses and arguments, and the literature presented in this section makes the case for this decision by revealing the large variety of studies that assume a certain definition of the term in exploring various means of 'integration' in design in construction without necessarily engaging in a conceptual analysis of the term. Therefore, in this section, the term 'collaboration' is used as an umbrella term, which covers various phenomena based on the different ways reviewed studies assumed and/or used it.

The studies that can be categorised under this group are greater in number and variety than those grouped as the studies of 'design management in construction' (see previous section). Cheng's (2003) paper, for example, investigates the variety of approaches adopted in researching design collaboration in construction. She reviews a ten-year period, and finds that many of those who study collaboration focus on design data exchange through computer systems, but also that a relatively smaller number of studies start from the human side, and look at how people think, how groups work together, or how people can work with computers (Cheng 2003). Therefore, this section reviews studies based on a variety of theoretical approaches and foci to provide an overview of the wide range of studies that can be grouped under the heading of 'design collaboration in construction'.

A significant amount of literature on design collaboration in construction focuses on communication and information management capabilities afforded by technologies (ICT), and draw strong linkages between these technological capabilities and design collaboration. Xue et al. (2012) reviews ICT-supported collaborative work in construction and finds that ICT for design in construction is a very active and intense area of research. In a similar study, Shen et al. (2010) review systems integration and collaboration studies from a technology-focused view and exposes the vast amount of studies on information and communication technologies that are released or being developed to support collaboration in construction design. Their conclusion is also a technology-centred one, and establishes technological capabilities as the enablers of better collaboration in construction while advocating for managing the change through adjusting people to the requirements of technology (Shen et al. 2010).

In this technology-centred stream of research, the main concern is to enable enhanced data or computer systems interoperability and access (i.e. technological integration) through, for example, 'cloud' computing (e.g. Wong et al. 2014), new technological architectures (e.g. Isikdag 2012), and improved technological standards (Shen et al. 2010). Advanced communication technologies such as augmented reality have also been promoted as collaborative technologies (e.g. Chi et al. 2013). However, there are also criticisms that the research on collaborative design in construction are mostly technology driven, and that organisational, people and business aspects are generally neglected; there is a strong tendency not to "*reality-check*" and not to study what the actual demands and issues from practice are (e.g. Shelbourn et al. 2007; Achten & Beetz 2009; Xue et. al 2012).

There are also a relatively smaller number of research that study 'design collaboration in construction' from a human activity and organisation perspective. These studies range from a micro-level, focused on human interactions, to macro-level, focused on industry scale organisational dynamics. For example, among those who have studied micro-level interactions, McDonnell (2009) analyses the design conversations between architect and building users in two meetings and concludes that "*collaboration occurring at different levels of granularity oriented towards deciding how to move the design along*" (McDonnell 2009: 49). In a similar vein, Luck (2009) studies how the design concept of a building is interactionally produced in the talk-in-interaction between an architect and client representatives, and states that "*design concept was observed to be significant for assessing why some moves in a design space were considered better than others*" (Luck 2009: 21). Another interesting example is the study of Luck (2012b) which shows that spatial reasoning in architecture can be seen as a sensible knowledge that enable architects to capture potential problematic aspects in designed spaces and articulate them so that solutions can be improved collaboratively. A further example is the study of Zerjav et al. (2014) who studied leadership-as-practice in a collaborative design workshop, and treat leadership "*as an emergent phenomenon that occurs through practices of interaction and relationships between diverse actors as opposed to an achievement by the supposedly successful leader-individual*" (Zerjav et al. 2014).

At the other extreme, the inter-organisational level (i.e. industrial organisation) has been studied in relation to collaboration. For example, partnering research attracted significant attention in the 1990s (e.g. Larson 1997; Thompson & Sanders 1998). Nevertheless, this movement has been criticised as underestimating the difficulties in enabling culture change both in individual organisations, and in the construction industry in general, upon which the expectations of improving collaboration through partnering was based (Bresnen & Marshall 2000). This stream of research has diverged over time, and similar, other, significant concepts such as 'project alliancing' and 'integrated project delivery' have emerged and attracted attention from scholars (e.g. Lahdenperä 2012). Among others who focused at the industry-level to understand collaboration, Davies and Brady (2016), for example, provide a conceptual model that connects organisational logic of a project to its wider environment, thus providing an explanation of how multiple organisations in a project deliver collaboratively, relying on the specialised knowledge and project capabilities embedded in a network of firms. In a similar line of thought, Jones and Lichtenstein (2008) argue that the social embeddedness in temporary interorganisational projects involves 'relational embeddedness' which provides shared understanding of roles, expectations, and 'structural embeddedness' which provides shared understanding of rules and procedures regarding collaboration. According to Jones and Lichtenstein (2008), these in turn create a 'macroculture' of collaboration which functions as a shared resource and rules of collaborating between the parties involved.

Another level of human organising that attracted significant attention is 'team' or 'project-level' interactions. For example, Chiu (2002) studies the relationship between design communication and the structures of the team and project to identify the influence of organisation on design collaboration. Those who adopted a rationalistic view of design and communication had the tendency to solely focus on ICT issues in the context of design collaboration at team or project level; such as Shen et al. (2010), as mentioned above. Those who have drawn on the ‘reflective practice’ view of design (Schön 1983) have looked at design collaboration at team level through the concepts of, for example, the ‘team mental model’ (Dong et al. 2013), and ‘team framing’ (Stumpf & McDonnell 2002) in order to explore the dynamics of ‘framing’ in interactions of designers. The term ‘shared understanding’ (i.e. between the members of the design team) has been generally used as the corresponding term for the view of design that emphasises social relationships, and includes an element of learning, knowledge creation and knowledge integration in its conceptualisation (Valkenburg 1998; Kleinsmann 2006; Arayici et al. 2005; Kleinsmann et al. 2010).

However, studies that adopt a practice-based view of design, direct their attentions to the accomplishment of the practical situation and, for example, study the contribution of visual and tangible materials in the successful organisation of the interdisciplinary design through the roles they play in visual and social practices (Whyte & Ewenstein 2007). A practice-based approach has also been previously employed to develop an understanding of collaboration as an ongoing project-level practical accomplishment. For example, Cicmil and Marshall (2005) study the practices of a construction project that went through a new tendering process and develop a conceptual framework for understanding the complexity of the project, thus providing a corresponding definition of collaboration that is based on coping with the complexity. Similarly, Gal and Hansen (2010) show how practices, discourses and material objects mutually shape each other resulting in a collaborative infrastructure enabling collaborative work in the construction project they studied.

Despite the significant amount of literature that can be considered to fall under the ‘collaborative design’ theme, it is a disputed concept and there is no widely agreed definition or theory about what it is (Kvan 2000; Achten & Beetz 2009; Wang & Oygur 2010). This has negative implications on the development of ICT, which claims to support design collaboration, because the conceptual lens used to look at the nature and process of design is primarily influential on the support technology that would be deemed appropriate (Kvan 1999). Design collaboration in construction is still an active research area that follows a number of different and largely disconnected trajectories focusing on human interactions (e.g. Luck 2015); ICT use (e.g. Zelkowicz et al. 2015; Mignone et al. 2016), and ICT development (Hu et al. 2016).

2.3.2.3. The role of design artefacts in organising the design work

In this section, the role of design artefacts in organisation of interdisciplinary design work is overviewed. Accounting for the materiality of practices is essential for a practice-based study, and design artefacts are the hallmark of the materiality in interdisciplinary design projects in construction. According to the Merriam Webster Dictionary, the word 'artefact' can be defined primarily as "*something created by humans usually for a practical purpose*". The artefacts produced and used over the course of design work, be they used to organise the design process (e.g. Gantt Charts, forms etc.) or the design output (e.g. plans, models etc.) are argued to be 'objects of interaction', and thus essential for communication (Robertson 1996; Perry & Sanderson 1998). Consequently, those who adopt a view of design that is socially-historically situated (i.e. including the practice-based view) claim that the design artefacts do more than passively carrying information between different parties of the design work; they mediate between the parties and practices in enabling intelligibility of design practices (e.g. Bucciarelli 1994; Perry & Sanderson 1998; Richter & Allert 2011). Perry and Sanderson summarises this argument as follows (1998: 286):

> "*Design work can no longer be adequately conceptualised in terms of individual 'intelligence', nor as a linear process with a set of design stages, but rather as a situation in which joint, coordinated learning and work practices evolve, and in which artefacts help to mediate and organise communication".*

It has been argued that such conceptualisation of design artefacts comes close to the concept of the 'boundary object' introduced in Section 2.2.3, in that the design artefacts concern interactions between divergent uses, needs and viewpoints (Richter & Allert 2011). It has been argued that design artefacts do not only provide common understanding, a fundamental basis for discourse and the pursuit of novel design ideas, but they afford different ways of framing, exploring, catalysing, inquiring, and probing and assessing what to do next, and what ought to be done (Richter & Allert 2011). This aspect of design artefacts led some scholars to conceptualise them as 'epistemic objects' (Ewenstein & Whyte 2009; Richter & Allert 2011; Nicolini et al. 2012). The 'performativity' of artefacts as 'epistemic objects' is argued to be instrumental in enabling 'intelligibility' and certain ways of doing things, over others (Miettinen & Virkkunen 2005). It has been shown that the same design artefact can be used as a technical-, boundary-, or epistemic-object, according to the situation (Ewenstein & Whyte 2009). The epistemic character of artefacts is closely related to their material and semiotic properties (Whyte et al. 2007; Richter & Allert 2011).

The findings of empirical research that study the technology-driven change align with these arguments. For example, Harty (2008) reports a case in which a planned project-based shift from pen-and-paper sketches and two dimensional (2D) Computer Assisted Design (CAD) drawings to 3D modelling faced strong resistance from the design team. He claims that people resisted because other material objects which were an integral part of designing and drafting were not considered. Consequently, new processes were seen as discontinuous with existing ways of working (Harty 2008). Similarly, Neff et al. (2010) show how digitalisation of artefacts in construction design can result in failures in communication that have implications for organising work. The following passage from Neff et al. (2010) gives one such example:

> "*Knowledge within BIM can also encode decisions that are not transparent to others or shut off negotiations around those decisions. In this particular setting, architects voiced the concern that a three-dimensional digital model reflects choices that were made to complete the artefact, not necessarily to represent the shared knowledge or decisions of the group. For example, when walls are presented in blueprints, they do not need to have a colour 'painted' on them as they do in a three dimensional model. Digital models may suffer from overdetermination, meaning seemingly technical choices that have political or organizational ramifications take on unintended significance and permanence*" (Neff et al. 2010: 568).

The arguments provided in this section show that design artefacts have active roles in enabling intelligibility in design practices, and therefore in the accomplishment of organisation in design work. Consequently, from a practice-based point of view, it is not only design artefacts' representational contents that need to be considered in exploring their contribution to the performance of interdisciplinary design work, but also their intermediary and performative aspects.

2.4. BIM, Interdisciplinary Design, and Technology in Organisations

This section presents literature on BIM and interdisciplinary design in construction, followed by a wider theoretical frame of technology in organisations. Section 2.4.1 starts with presenting the dominant promotional rhetoric of BIM which focuses on its technological capabilities to enable more collaborative design. This is based on a particular view of 'collaboration in design' (see Section 2.3.2.2 for an overview of different views and approaches) which frames interdisciplinary design work around data transactions. Following this, Section 2.4.1 presents the research that are critical of focusing solely on technology in understanding interdisciplinary work in BIM-enabled projects. Among these, a particular attention is paid to the recent empirical organisational research on BIM, which studies the practices of working in BIM-enabled projects. This growing body of research reveals the organisational challenges triggered by the adoption of BIM, and hence, establishes that it has unanticipated, and at times, counterproductive organisational impacts, rather than being an isolated tool that enables improved 'collaboration' in a straight forward way (Harty 2008; Harty & Whyte 2009). The following Section 2.4.2 presents wider literature on technology and organising to place the organisational research on BIM in the wider theoretical context which enables a broader perspective.

2.4.1. Organisational challenges of BIM

Design in construction requires different professionals with different backgrounds and foci to work together in order to deliver value for the client and for the physical environment of the building. In such practice, communication between different members of the design team becomes of utmost importance, as each possesses different sets of skills (Sebastian 2011). Consequently, the efficiency of interdisciplinary work during the design phase of construction projects is regarded as a critical success factor (van Leeuwen 2003). As stated in Section 2.3.2, it is believed that the construction industry underperforms and fails to deliver optimum value for its clients (e.g. Latham 1994; Fernie et al. 2006). It is also believed that the most important reason behind this is the lack of communication and coordination between different stakeholders of construction projects, which results from the 'fragmented' nature of the industry (Tam 1999; Deraman et al. 2012; Grilo et al. 2013). Traditionally, 2D drawings and text documents have been used to exchange project information between different professionals involved in design. Although different design disciplines have been using 3D models, more-sophisticated visualisation and analysis tools for design development and information exchange have remained more-or-less 2D-based until recently (Singh et al. 2011). The traditional processes for information retrieval, interpretation, and communication of complex design information from 2D drawings and documents have been argued to be often time-consuming and difficult; and hence they have been seen as the main reason for the problems in interdisciplinary communication and coordination (e.g. Zaneldin et al. 2001; BIM Industry Working Group 2011; Azhar et al. 2012).

Among the solutions proposed, Building Information Modelling (BIM) has become a significant topic for the construction industry due to governments' requirements for its use (e.g. UK Cabinet Office 2012), its reported potential benefits (e.g. Azhar 2011), and consequent business improvement expectations (Gu et al. 2008; Grilo & Jardim-Goncalves 2010). BIM can be defined as the process of development and use of a digital model of the facility intended to be built. The resulting product of BIM, the building information model (information model/model henceforth), has the ambition of being the central hub for all information about the facility from its inception onwards. This information may take on many shapes and has many roles to play for the whole life cycle of the facility (BIM Industry Working Group 2011). The conceptualisation and use of the model as the central hub requires all stakeholders in the project to add to a shared data repository through a coordinated effort. This data can be used by all the actors throughout the whole life-cycle for different purposes (BIM Industry Working Group 2011; UK Cabinet Office 2012).

BIM tools allow 3D visualization of design as well as inclusion of rich, non-geometric data such as object attributes and specifications in building information models. Besides, there are applications such as design analysis, design error checking, facility management and so on, which are able to exploit the data embedded in models (e.g. Love et al. 2014). Therefore, BIM is considered as an Information and Communication Technology (ICT)-enabled approach that allows better management and representation of building information during a project's life cycle (Fischer & Kunz 2004). As a result, there is a strong belief that BIM applications' visualisation capabilities (i.e. 3D) as well as their ability to directly use and exchange rich building data, present opportunities for enhanced 'collaboration' and 'distributed (group) project development' (Grilo & Jardim-Goncalves 2010; Singh et al. 2011; Azhar et al. 2012; Shafiq et al. 2013; Oh et al. 2015). Therefore, the data storage and management capabilities of BIM technologies are seen as having potential to improve the performance of the construction industry (BIM Industry Working Group 2011; UK Cabinet Office 2012). Consequently, there is strong emphasis on 'collaboration' through interdisciplinary design data sharing in BIM-related policies (e.g. BIM Industry Working Group 2011, BSI 2013), and in BIM-related research (e.g. Shafiq et al. 2013; Wong & Fan 2013; Oh et al. 2015).

The data storage, management and sharing capabilities of technologies of BIM stand upon the 'interoperability of ICT'. 'Interoperability of ICT' refers to the ability to exchange data between different software packages (Ide & Pustejovsky 2010). In BIM-enabled design projects, ICT interoperability allows different design team members to contribute to and use data from a shared data repository within which design data are stored in a unified and structured way. This is referred to as 'integration', in the sense that design data from different design team members are linked through pre-defined and/or user-defined rules (i.e. parametric design) (e.g. Whyte 2011; 2013). Therefore, such digital integration of design data has been promoted as an enabler of better design-team 'collaboration' in BIM-enabled projects; this includes enhanced (and sometimes automated) data generation, analysis, presentation and sharing capabilities (e.g. BIM Industry Working Group 2011).

However, despite these apparent technological capabilities, it has been argued internationally, that the adoption of BIM is not as rapid as had been anticipated (Azhar 2011; Gu et al. 2008; Gu & London 2010), and its full potential has not been realised where it is implemented (Brewer & Gajendran 2012). A recent report on international BIM adoption and use in construction design (NBS 2016) shows that a significant number of firms has not yet adopted BIM, and the majority of firms are not clear about what it is. Furthermore, the countries that have the highest BIM adoption rates in NBS (2016) (i.e. Canada and Denmark), reported the 'lack of collaboration' as a barrier to BIM, implying that BIM adoption does not necessarily lead to 'collaboration', and indeed fruitful 'collaboration' precedes the effective adoption and use of BIM on a project. This raises questions about the role of interoperable BIM technologies in enabling interdisciplinary design work. A significant amount of the literature into BIM in construction claims that technology alone cannot enable improvements in interdisciplinary work in construction. Rather reaching a delicate balance between technological, organisational and people issues are required for achieving successful interdisciplinary work in BIM-enabled projects (e.g. Akintoye et al. 2000; Shelbourn et al. 2007; Homayouni et al. 2010).

ICT interoperability, upon which the promoted technological capabilities of BIM stand, requires specified data formats, communication protocols, and other formal structures to enable communication and data exchange between different software packages (Ide & Pustejovsky 2010). Therefore, in this new BIM-enabled design-production situation, 'collaboration' is defined by, or at least framed by, data interchange. However, 'collaboration as mutual engagement of people' (i.e. as an organisational issue) is less clearly addressed by data interchange, and the implications of mediating human and organisational interactions with ICT tend to get lost in this framing (e.g. Neff et al. 2010). This has been seen as a serious problem by those who found that the primary condition to achieve successful 'collaboration' is the establishment of right social and organisational foundations; and technology, whether paper drawings or building information models, needs to support these foundations by facilitating transparent and reliable communications (e.g. Homayouni et al. 2010; Dossick & Neff 2011). In line with this, it is argued that the inability to realise the full potential of BIM is connected to people issues (Neff et al. 2010; Brewer & Gajendran 2012). In a similar way, Hartmann et al. (2012) criticise the top-down, technology-push approach that dominates the BIM implementation literature. Here, the top-down, technology-push approach suggests that business processes need to be aligned to a new way of working that BIM requires for them to be beneficial. Hartmann et al. (2012) do not imply that most of the existing work does not consider people issues, but rather suggests that their problem-definition and problem-resolution are more technology-centred.

Therefore, it is widely acknowledged that in addition to technology implementation, BIM implementation should also include process- and organisational-changes to realise its potential benefits that rely on its technological capabilities; and these changes need to consider 'people issues' (e.g. Gu & London 2010; Arayici et al. 2011; Olatunji 2011; NBS 2016). In consideration of this, Harty (2008), and Jacobson and Linderoth (2010) suggest to view the relation between ICT and people in construction projects as intertwined, and to analyse them as mutually shaping heterogeneous entities.

Findings of the growing body of organisational research on BIM and interdisciplinary design support these arguments by providing empirical evidence, and hence, raise questions about the role of BIM technologies in enabling interdisciplinary design work in practice. This body of literature challenges the technology-centred view of BIM-enabled 'collaboration' by focusing at the practice, in which people and technology mutually shape each other in unpredicted ways. Whyte and Lobo (2010), and Whyte (2011) show that digital integration of design data has significant effects on the way design projects are organised. Furthermore, Neff et al. (2010), and Dossick and Neff (2011) reveal that these effects can become counterproductive for interdisciplinary interactions depending on how interoperable ICT is framed and used within the project organisation. For example, Dossick and Neff (2011); and Whyte (2013) show organisational situations in which the formal, rule based, and linear logic of BIM was obtrusive on interdisciplinary, iterative, physically applied, and dynamic character of construction design. Dossick and Neff (2011), and Whyte (2011) show that in practice, these situations need to be negotiated to be settled, and lead to improvised combination of digital and non-digital practices to enable the successful accomplishment of the work. Therefore, Whyte (2013) urges for new approaches for studying digitally-integrated construction-design work to critically question the role of interoperable ICT in practice. Consequently, the arguments provided by the recent organisational research on BIM and interdisciplinary design, which introduces the problems of mediation of interdisciplinary design by BIM technologies, is particularly relevant here.

The findings of Whyte and Lobo (2010) show that digital integration of design data couples the members of the design team closer, and challenges the conventional boundaries between organisations, disciplines, teams and roles in the design project. Therefore, work, involving the integrated data, needs to be highly regulated and formalised in order to be accountable. Nevertheless, Whyte and Lobo (2010) argue that although the interoperable software is set-up to be an integral part of the established formal control structure, control is never total, but rather the boundaries, methods, objects and goals are negotiated (Whyte & Lobo 2010). Similarly, Dossick and Neff (2010) claim that BIM-enabled projects that have closer technological coupling, do not solve the inherent conflicts between different members of the design team, but make the boundaries more visible and harder to cross (Neff et al. 2010). This requires more leadership to make collaboration possible (Dossick & Neff 2010).

The interoperable ICT connect various stakeholders with different needs in a rigid way and assume a singular reality, and so impose the rules codified in the technologies. Whyte (2013) shows the shortcomings of this for design in construction that has a future physical application. She argues that, in construction, designers cope with the complexities of the physical world through testing their design from multiple perspectives, and interoperable ICT is limited in these terms (e.g. designers benefited from using physical models in addition to information models) (Whyte 2013). She proposes open information systems for construction design work "*in which an evolving and partial digital infrastructure can be used to achieve goals beyond the computer*" (Whyte 2013). Neff et al. (2010), and Dossick and Neff (2011) argue that centralisation and integration of design data produces over-determination and inflexibility in design, and makes it harder to encompass interdisciplinary design settings that require integration of multiple perspectives. Dossick and Neff (2011) suggest that interoperable ICT should be continuously complemented with informal communication to overcome this shortcoming. Later, Dossick and Neff (2014) focus on documentation in BIM-enabled design projects and argue that there is a cost associated with the fixity that is established by documentation of information in an integrated data repository. They claim that "*the price of documentation include[s] an opportunity cost of unimagined solutions as well as the real cost of labour to modify models once developed*" (Dossick & Neff 2014). Similarly, Merschbrok and Wahid (2013) study task interdependencies, technological interdependencies and the positions of stakeholders in the process-chain in construction projects. They conclude that in BIM-enabled projects, due to the specific ways information is documented and integrated (i.e. forms and formats of information), those who are handed previously documented information are less flexible in their undertakings.

Recent research on BIM and interdisciplinary design has also shown that there is a considerable ongoing joint effort of different design team members for the set-up and operation of interoperable ICT as anticipated (Whyte 2011; 2013; Jaradat et al. 2013). Whyte et al. (2016) argue that the rapid and flexible forms of project organisations, that were unlocked by interoperable ICT, have limits in practice because of the lack of trust in the integrity of the information. Whyte (2011; 2013) argues that working with interoperable ICT requires undertaking processes outside of core design-tasks so that the success of an integrated technological infrastructure is always fragile and only ever partly accomplished (Whyte 2013). Furthermore, Jaradat et al. (2013) claim that the ongoing efforts to keep the digital systems functioning became a central task in the project they studied and this created new roles and forms of accountability which conflicted with historically established practices.

2.4.2. Theorising technology and organising

This section presents selected research that builds theory about the relationship between technology and organising from a wider perspective, beyond the context of BIM and design in construction. Scholars of 'technology and organising' provide arguments and generalisations that support the findings presented by organisational research on BIM (see Section 2.4.1), and thus their work are relevant here. The studies reviewed in this section investigate the relationship of technology with different levels of organisational life (inter-organisational, organisational and practice levels). Therefore, they employ a variety of approaches in their theorisation of technology and organising.

According to Beynon-Davies (2011), technologies are fundamental in organising because they are essential in producing patterns of representation, communication and performance which create recognizable and meaningful practices. It has been argued that interoperable technologies in particular have significant effects on organisational life because they connect different organisations with significantly different social worlds through technological standardisation (Kallinikos 2006; Mutis & Issa 2012). Findings from various professional domains have shown that technologies in general, and interoperable technologies in particular, are not only technical devices but also have considerable effects on social aspects of organisations such as organisational structure, roles and control mechanisms, and therefore on accountability (Kallinikos 2006; Orlikowski 2007; Gherardi 2010). In a similar line of thought, Weick (1990; 1995) argues that technology does not only affect practice-level 'sense-making' of practitioners by structuring aspects of the situation in which they find themselves, but also their understanding of the way work is organised. Consequently, different - but connected - effects of interoperable ICT on different levels of organisational life have been studied in organisational research.

Inter-organisational Technological Standardisation for Technological Interoperability

Gherardi (2012: 2) claims that, from a practice-based perspective, 'organisation' can be conceived as "*a 'texture' or 'web' of practices, which extend internally and externally to the organisation*". This constitutes a mode of ordering the flow of organisational relations, and therefore defines accountability principles at different levels of organisational life (Beynon-Davies 2011; Gherardi 2012; Nicolini 2012). In line with this argument, Kallinikos (2006) considers inter-organisational level, and claims that standardisation for technological compatibility between different organisations is a major determinant of the practices that take place in these organisations. According to Kallinikos (2006), this is because the terms and logic of standardisation induce patterns of activities in the organisations that use compatible technologies. When seen from this perspective, such standards also establish the basis for further standardisation of technologically-connected organisations and their work processes (Fountain 2001; Kallinikos 2006). Williams et al. (2004) concur with this argument, and claim that compatibility standards do not only technically define the rules for the interoperation of different pieces of technology, but most importantly they represent proposals for the future of complex socio-technical work systems.

Effects of Interoperable Technology on Organising and Practice Level

Organisational-level impacts of technologies of work had been a topic of interest for organisational research even before inter-organisational information and communication technologies (ICT) emerged. In earlier accounts of research in technology, work, and organising, Woodward (1965) and Perrow (1967) argue that technologies are determinants of task structures that are essential for the establishment of organisational structures, and thereby communication and control structures. This claim is in line with Barley (1996) who claims that technology, organisation, and work co-evolve; therefore, no organisational structure can be optimal unless it is tailored to the technology and the work it seeks to systematise. Both Kallinikos (2005; 2006), and Suchman (2007) concur with these arguments, and extend them to contemporary (and interoperable) ICT with a consideration of the remarkably high pervasiveness of contemporary ICT in all aspects of organisational life. Kallinikos (2009) suggests that the pervasiveness and outreach achieved through 'computational rendition' of all aspects of life does not necessarily mean that organisations are 'freed' from the organisational impacts of technology, but rather mean that these impacts have been made more prevalent. Studies of Kitchin (2014), and Tuomi (1999) on the nature of digital data suggest that one of the main reasons for this, is the fact that 'data' are never pre-factual or neutral, but always fashioned towards certain ends in the service of certain needs and perspectives. These claims resonate with the argument that information and communication technologies have 'materiality' (Leonardi, 2010) due to the particular ways in which they affect practices, in that they systematically constrain, allow, encourage, facilitate, remind, invite and so on, certain courses of actions over the others; and thus, shaping organisations.

Suchman (2007) shows that such effects on practices are not necessarily in line with, or adaptable to the unpredictable contingencies inherent in everyday practices. She claims that ICT actions are fundamentally planned, and therefore ICT have limited application to the unfolding social situations and their significance for humans. The real concern then, she argues, is to understand what happens at the interface between the human and ICT where the planned course of action imposed by ICT coincides with practitioners' situated needs. She proposes the notion of 'ordering device' to understand this interface. Her discussion reveals that ICT, as any other ordering devices such as plans and scripts, systematically transform practices in rather subtle ways through the perceptual, communicational, organisational, and control structures that they embody and enable; and thus, changing the organisation of work (Suchman, 2007).

This resonates with Weick (1990) who claims that when working with modern technologies, technology becomes a strategy for action and not just a tool; thus, it does not only affect practice-level activities but also practitioners' understandings of the way work is managed. Other research also provides similar arguments, and claims that technologies can be used as strategic instruments in regulating the way in which work is organised. Among these, Luhmann (1993), and Lampel and Mintzberg (1996) argue that use of technology can be considered as a major control and efficiency strategy, which is based on the need for keeping environmental variations (that technology cannot respond to) to a minimum. They argue that this strategy is based on standardisation of work processes and outputs based on the standard ways of working of technological infrastructures (Luhmann, 1993; Lampel & Mintzberg, 1996). Similarly, Kallinikos (2006) claims that technological interoperability digitises the task infrastructure and standardises the inter-organisational work processes and outputs, thereby creating significant shifts in the task structure, communication and control mechanisms, and consequently in the organisational structure and behaviour.

The organisational literature that scrutinises the ways in which practice-level activities unfold, provide similar arguments. These studies suggest that, in organisational practices, technologies do not only provide material resources as objects to interact with, but also social resources as vocabularies and cognitive frameworks to practitioners for making sense of the situations (Weick 1990, 1995; Gherardi 2012). Similarly, Styhre (2010) studies ICT-mediated vision, and concludes that it is not neutral, but a result of a particular underlying logic and assumptions that are inscribed in ICT, and, therefore, intimately associated with corresponding particular 'modes of seeing'. Mackenzie's (2008) study of financial markets provides an empirical example for this argument by showing how financial (mathematical) models that run on numerous interoperable technologies become 'engines' that drive the financial markets rather than 'cameras' that give a full-picture of what is happening. Virilio (2005) criticises these hindsight- and ordering-effects of ICT mediation on practice-level meaning-making (especially when many aspects of the work are digitised through interoperable ICT) by stating that this makes people merely 'reviewers' of the world rather than truly 'seers' of it.

Further, according to Weick (1990), inter-connected technologies are equivocal, and this has serious implications on practice-level meaning-making which ultimately result in certain organisational behaviour. He argues that when the number and variety of the operations that are mediated by ICT increase, the technology becomes equivocal, because of i) the abstract nature of the way ICT function; ii) a series of automated operations by ICT would otherwise be local and unlinked; and iii) the gap between the operational model inscribed in the ICT and the model in the practitioners' minds (Weick 1990). Kallinikos (2006) makes a similar point and claims that interoperability of ICT amplifies these equivocal effects, reduces the capacity of appropriation of technology based on the local (i.e. situated) needs of practices, and therefore, makes the practice-level meaning-making subject to digitised and centralised control structures.

CHAPTER 3. METHODOLOGY

3.1. Introduction

The practice-based approach adopted in this research considers 'practice theory' in relation to the following three ways of studying 'practice' (i.e. the empirical phenomena): an empirical orientation to exploring how people act in organisational contexts; a theoretical orientation to understanding relations between the actions people take and the structures of organisational life; and a philosophical orientation on the constitutive role of practices in producing organisational reality (Feldman & Orlikowski 2011). As stated in Chapter 1 - Introduction, definition of 'practice theory' seems in contrast with the general view of 'theory' which can be defined as "*a formal system of hypotheses that generate explanations and predictions*" (Stern 2003: 187). The present study follows the 'practice theory' ethos conveyed by Stern (2003: 187):

> "*…there is… a much more open-ended sense in which the term 'theory' is used for any general or systematic way of approaching a given subject matter, a usage which includes such activities as providing models, offering exemplary studies of particular cases, developing conceptual frameworks or categories, or providing a genealogy, and it is in this sense in which 'practice theory' is a theory*".

Consequently, approaches and methodologies that can be considered as 'practice theory' share some principles as presented in the Literature Review (Chapter 2). However, there is no unified 'practice approach' (Schatzki 2001) and 'practice theorists' are an unusually diverse group (Stern 2003) in their fundamental conceptions of, for example, 'activities' and 'agency' (Schatzki 2001). Consequently, the philosophical, theoretical, and empirical orientations of the present research require more explanation. Nicolini (2012) claims that, in practice-based research, it is allowed (and even desirable) to adopt a 'toolkit approach' that is based on mixing-and-matching the strengths of various practice-based perspectives and methodologies, which are based on the same philosophical underpinnings. Following Nicolini (2012), the present research does not adopt a single, previously established practice-based approach or methodology but develops its philosophical, theoretical, and empirical orientations through discussions about the particular needs of the study, and the insights gained from the previously developed practice-based notions, approaches and methodologies.

Next section, Section 3.2, establishes the philosophical orientation of the study by considering the practice-based view of ontology/epistemology, and the problematic nature of exploring BIM-enabled interdisciplinary design in construction. Section 3.3 establishes the theoretical orientation of the present research. It first outlines how 'practice thinking' is used to make sense of the collected data (Section 3.3.1). This is followed by a discussion of how the present study sets the different research questions, which are addressed in each of the findings and analyses chapters, to build theory (Section 3.3.2). Section 3.4 establishes the empirical orientation of the present study. It starts by introducing 'ethnography' as a methodological and analytical approach to social research, and providing explanations about its use in this study (Section 3.4.1). This is followed by the presentation of the details of data collection (Section 3.4.2) and data analysis (Section 3.4.3) processes of the present research. These are complemented with an explanation of the author's personal perception about the process of undertaking the present research and his personal profile (Section 3.4.4). In Section 3.4.5 a reflective account of how this study deals with the inherent challenges of doing ethnographical research is provided. Finally, the background information about the projects that were observed in this study are presented in Section 3.4.6 in order to provide the general context for the empirical findings and analyses of the study.

3.2. The Philosophical Orientation of the Study

The problem of investigating interdisciplinary design work in construction, and the effects of ICT mediation on this, are complex. First, investigating interdisciplinary design work in construction is complex due to its multidisciplinary, developing and dynamic nature. The relationships between design stakeholders and the design objects that they are using constantly change, requiring the organisation to change in order to make interdisciplinary work possible (Ewenstein & Whyte 2009). Second, investigating technology in organisations is also complex because of the mutually constitutive nature of technology and organisations. Leonardi and Barley (2008) argue that theory builders studying the interactions of people and technology in organisational settings inevitably find themselves contemplating the line between material and social; "*a line that looks less solid up close than it does from a distance*" (p. 159). Different approaches such as the ones adopted in innovation studies (Downs & Mohr 1976), Adaptive Structuration Theory (DeSanctis & Poole 1994), and Sociomateriality (Leonardi 2013) have been proposed and employed to conceptualise the entangled nature of social and material/technical entities in organisational settings. A practice-based understanding of ontology/epistemology (Gherardi 2012) can deal with the complex nature of technology-mediated interdisciplinary design work through the 'relational epistemology' that it suggests. Such a relational epistemology addresses the complexity arising from the multidisciplinary and evolving nature of the interdisciplinary design work, as well as the complexity arising from the mutual shaping of technology and organisational practices.

Two fundamental characteristics of interdisciplinary design in construction posit two methodological challenges for the present research. First, construction design is notional work without any physical referents, and therefore, it primes intangible meanings (Schmidt & Wagner 2002). Since it is 'interdisciplinary' work, it can be argued that there are different discipline-specific (and individual) meanings attached to the same design (e.g. Harty 2005; 2008). This implies an ontological split, and thus implying a methodological challenge for research. Second, design is achieved through constant change, a non-linear becoming trajectory (Neff et al. 2010), as a consequence of the complex web of interdependencies and interactions between different practitioners and objects. Therefore, perceptions of various practitioners constantly change, and also rely upon different discipline-specific ontologies (Mutis & Issa 2012). This implies multiple epistemologies, and thus implying another methodological challenge for research. Consideration of these challenges reveal that a realist ontology or a positivist epistemology have significant shortcomings for studying interdisciplinary design work which is notional, and constantly changing.

Similarly, regarding the study of information and communication technologies (ICT) and organising, it has been shown that the same technology is used in different ways in different organisational settings (e.g. Edmondson et al. 2001). This produces an ontological split, and a challenge in conceptualising the technology. However, it has also been shown that information technologies cause significant changes in traditionally established organisational practices (e.g. Zuboff 1988), suggesting an epistemological challenge. In other words, if the technology changes the traditional practices, and the traditional practices affect how information technology is used and perceived, then; what is real? (i.e. ontology); and how one can know about it? (i.e. epistemology). In this regard, realist ontology and positivist epistemology have also shortcomings for studying technology and organising.

Hence, this research attributes a social constructionist conception to practice that does not distinguish between production of knowledge, and construction of the object of knowledge (i.e. between ontology and epistemology). In other words, the 'activity of practice' is used as an epistemology (Gherardi 2012). This has advantages in dealing with the methodological challenges outlined above.

First, the adopted practice-based approach transforms the ontology/epistemology distinction which is problematic when studying interdisciplinary design in construction.

According to the adopted approach, the design project under investigation can be an architectural project for the architect, a mechanical project for the mechanical engineer, a source of new jobs for neighbours, or another 'box to tick' for the planners. In other words, what a design project is depends on the situation. Besides, the adopted practice-based approach can also deal with the epistemological challenge of studying interdisciplinary design in construction by providing a relational materialist epistemology. A relational epistemology focuses on processes or in dynamic, unfolding relationships (Emirbayer 1997). Such an epistemology emphasises relations of reciprocal determination, and therefore aligns with the interdependent, interactional character of interdisciplinary design work. Practice-based studies have the ability to explain how all the differences inherent in people and objects interact in complex ways, but still produce recognisable practices over time, thus, creating order and useful meaning for design practices (Schatzki 2001; Nicolini 2012).

Similarly, the adopted practice-based view of technology in organising suggests that neither technology nor organisational practices determine the other. Rather they are mutually constitutive (i.e. relational), in the sense that what they are depends on the interrelations between the features of technology and the particulars of organisational practices. Therefore, the technology has the power to transform the organisational practices through the particular ways of working that it enables, encourages, foregrounds and so on. However, its particular meaning and use depend on the way organisational practices can make sense of, and use it. This mutual constitution points to an ongoing relationship between the technology and organising that can provide explanations that avoid both technological determinism and human voluntarism, which are challenged empirically (Leonardi & Barley 2008). This is of particular importance in the study of interoperable information technology where one organisation's output is technologically translated to others' input; thus requiring adoption of an appropriate ontological/epistemological position to capture the changing ontological and epistemological positions in practices.

According to Nicolini (2012) all practice-based theories and methodologies that study practice as 'the house of the social' are built on the work of two German philosophers Martin Heidegger and Ludwig Wittgenstein. Nicolini (2012) claims that those who wrote about the constitution of social order by putting the practices at the centre of their inquiry are inspired by these two philosophers who initially developed the philosophy:

> "*that phenomena such as knowledge, meaning, identity, activity, power, language, social institutions, and transformation are 'housed in' and stem from the field of social practices*" (Nicolini 2012: 162).

Although there is no total agreement among these various practice-based theories and methodologies, Nicolini (2012) argues that they all contribute to a common project, according to which practices represent the basic component of social affairs, and as such they constitute the basic epistemic object of social theory. Nicolini (2012) states that, in this view, human affairs are theorised by inquiring into practices and their connections, rather than human agency or structure: commonly held positions in social sciences (e.g. Hays 1994; Fuchs 2001). In social sciences, the agency and structure split has been criticised as being either mutually exclusionist or incommensurable, thus, having shortcomings for developing explanatory theories that cover both micro-level interactions and macro-level effects (Fuchs 2001). Research in technology and organisations has also criticised propositional subject/object distinctions, or the distinction between technological determinism and individual voluntarism for the same reasons (e.g. Leonardi & Barley 2008). Similarly, Sandberg and Tsoukas (2011) claimed that 'scientific rationality' - based on the distinction between ontology and epistemology - does not deliver practically relevant explanations for management research, and they proposed adoption of 'practical rationality' based on Heidegger's views on ontology/epistemology.

A practice-based view reconciles the propositional micro-macro, subject-object and social–material distinctions that have been criticised (Feldman & Orlikowski 2011). Since the 1990s the practice-based theories and approaches have been increasingly employed to build theory about various complex phenomena, and increased interest in practice-based view has led to 'the practice-turn in contemporary theory' (Schatzki 2001). Information systems research, and organisational and management studies are two areas that used practice-based thinking to study organisational- and ICT-mediated- complex phenomena. In these areas Heidegger's alternative to the ontology-epistemology distinction enables researchers to develop more-practically relevant theorisations of both organisations and technology (e.g. Sandberg & Tsoukas 2011; Riemer & Johnston 2014). The general outline of Heidegger's alternative to propositional subject/object or ontology/epistemology distinction is given in Chapter 2. It is clear that the present research's ontological and epistemological assumptions align with Heidegger's view of 'being-in-the-world' and how things find their meanings (i.e. give themselves to people) in a relational whole, which is established in and through interactions between human and non-human entities (see also Sections 3.3.1 and 3.3.2).

3.3. The Theoretical Orientation of the Study

3.3.1. Building theory through 'practice thinking'

This section provides an explanation of how 'practice thinking' is used to build theory (based on empirical data) in the present research. This is further detailed in the next section through a discussion about the formulation and use of different research questions, which are addressed in different findings and analysis chapters (Chapters 4, 5, and 6), for theory building.

A practice-based theoretical orientation (Schatzki 2001; Stern 2003; Nicolini 2012; Gherardi 2012) allows both exploring the practice-level, where 'meaning' is created, and making associations between the practice and higher (i.e. more abstract) organisational levels such as project-level or industry-level. This generates theory that enables associations between everyday activities that can be empirically observed at practice-level, and organisational order (i.e. organisational routines, structures, and patterns) which can only be identified in abstract terms (i.e. at more abstract levels of organising) (Feldman & Pentland 2003; Feldman & Orlikowski 2011). A focus on the everyday activities performed in practices is promising for investigating ICT-mediated interdisciplinary design in construction projects for three main reasons.

First, although routine aspects of organising projects provide the basis for interaction, routines are also incomplete, performative, and involve an improvisational component for dealing with unique and non-routine aspects of practical situations (Feldman & Pentland 2003; D'Adderio 2008; Hällgren & Söderholm 2010; Gherardi 2012). A practice-based investigation is useful in exploring what improvisation are mobilized to efficiently deal with unique situations. Consequently, studying projects-as-practices (Hällgren & Söderholm 2010) has the potential to provide valuable insights into what is mobilized and how, to practically accomplish interdisciplinary design work; and hence, has the potential to have important implications both for ICT development and organisational management.

Second, following from the previous point, digital organisational practices are argued to be driven by the imperatives of bricolage, improvisation, self-organisation and adaptability (Grabher 2002). The practice-level, where meaning-making occurs, is the most relevant to explore the patterns of, and underlying reasons for these phenomena, which are found extensively in the inter-organisational interactions when the technological interoperability is enabled. Consequently, practice-level explorations have the potential to reveal the origins of the effects of ICT on interdisciplinary work, which can then be managed.

Third, it has been argued that the mutual shaping of ICT and social practices (i.e. entanglement) takes place through everyday performances at practice-level, creating a history of sociomateriality (Orlikowski 2007) which eventually leads to transformed ICT and organisations. In this regard, a focus on everyday activities in practices can reveal many important phenomena about the process of mutual shaping that may be hard to identify when the investigation is limited to the aggregated social processes or structures (Hällgren & Söderholm 2010). Consequently, a practice-based investigation exposes the journey of mutual shaping, shows how mutual shaping alternates and what the consequences are (Gherardi 2012); thus, providing insights into how criteria for policy-making as well as for technology and organisational management need to be decided.

However, in order to be able to articulate the implications of findings from everyday activities at practice-level, on technology development, project management or policy making; these findings need to be associated with more-abstract (i.e. higher) levels of organising (i.e. organisational structures, routines, and patterns). The relational epistemology of practice-based studies acknowledges that 'local' (i.e. practices) and 'global' (i.e. organisations, industries) are interrelated epistemologically. In this respect, the explanatory power of practice-based view lies in its capability of establishing associations between different levels of organising (Nicolini 2012). Consequently, both the exploration of practice-level activities where meaning making occurs, and the higher organisational levels are required (Gherardi, 2012). Such an exploration can expose the underlying logic that leads to chosen courses of action in practice, and relate this to more-abstract (i.e. higher-level) organisational phenomena to provide practically relevant explanations. This involves 'zooming-in' to practices, and 'zooming-out' to higher (i.e. more abstract) levels, such as ordered organisations (Nicolini, 2012). 'Zooming-out', in this regard, corresponds to observing the dominant discourses, discussions and processes within an organisation and beyond, in the wider field (Nicolini, 2012). Here, a researcher interprets the collected practice-level empirical data through his/her understanding of the wider organisation and field. The rigour of such interpretations is ensured through the description of the local-global associations that align with empirical findings.

Nevertheless, working at different levels of organising that are argued to be mutually dependent is linguistically problematic for several reasons. First, a practice-based view suggests that all kinds of effects that can be identified through the analysis of different levels or aggregated accounts of organising (e.g. situational, structural, cognitive effects and so on) come together in entangled ways in practice and are re-produced, re-appropriated, re-confirmed through the actions of practitioners (Gherardi 2012). Therefore, a ‘frame’ consisting of an empirical focus to foreground certain aspects of practices and a developing vocabulary to capture the relations among various levels of organising (i.e. levels of abstraction), is required to describe, understand, analyse, and discuss practices (Leonardi 2013). In this research, this requirement is dealt through setting distinct research questions (and empirical foci) that underpin different ‘frames’ for each of the three findings and analysis chapters. The consistency (i.e. commensurability) between these ‘frames’ are shown through the discussions held in Section 3.3.2 in this chapter.

Second, the language and concepts used in these ‘frames’ must be in line with the ontological and epistemological assumptions of the adopted practice-based approach (e.g. using verbs instead of nouns, such as ‘organising’ instead of ‘organisation’). Relational epistemology suggests that ‘agencies’ are continuously re-configured according to the changing circumstances of unfolding situations (Gherardi 2012). Therefore, when relational epistemology is adopted, the concepts that are used and developed must reflect this dynamism. Consequently, concepts used and developed in practice-based studies need to be carefully adjusted to reflect both order and disorder, and both change and stability inherent in unfolding practices (Gherardi 2012). This suggests that, in the present research, the concepts need to reflect the variety of activities undertaken by various design practitioners who respond to developing design situations, but they also need to reflect that each of these activities contribute to the ongoing accomplishment of organising and order. Similarly, Langley et al. (2013) argue that theorisation in studies that adopt a ‘process ontology’ (i.e. a changing ontology) are expected to deliver dialectical and evolutionary process models that are based on multi-level interactions that explain the processual dynamics of stability.

According to Langley et al. (2013), this can be done in two ways for the studies that adopt a ‘process ontology’ (like the present research). One way is to create a ‘process story’ as an abstract conceptual model, which identifies the plot or generative mechanism at work. A second way is to identify and make analytical generalisations to the general case of which the study is an instance (Langley et al. 2013). This research employs both ways in each of the analysis and findings chapters (Chapters 4, 5, and 6). Each of these chapters presents plots (i.e. narratives about a generative mechanism) based on empirical data, and finishes with an overarching discussion through which an explanatory organisational concept is developed. A diagrammatic representation of the theory building strategy adopted in this research is shown in Figure 3.

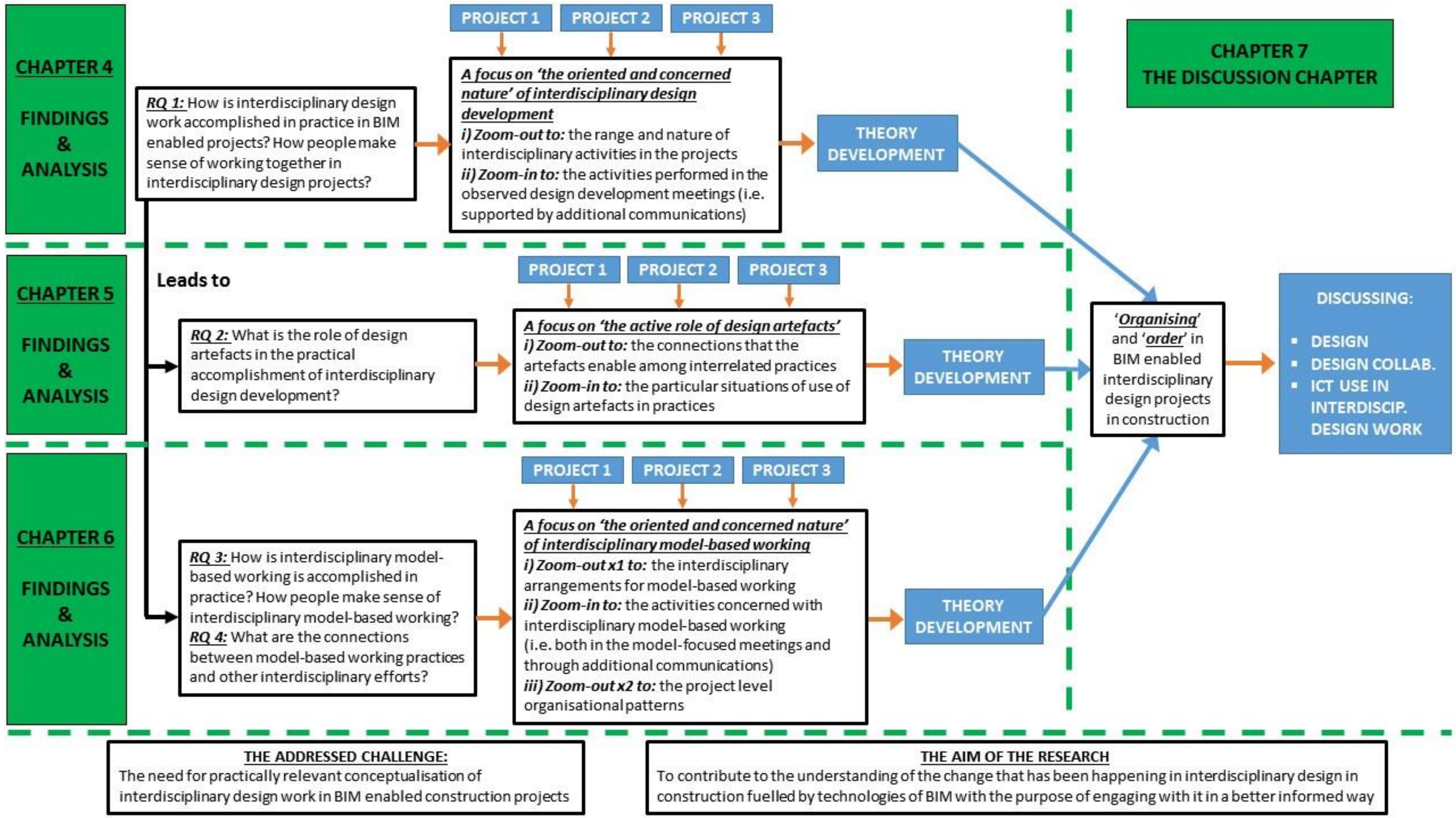

Figure 3 - Theory building strategy of the research

3.3.2. The role of the research questions in theory building

In the previous section, it has been stated that description of, and theorisation from practice-level activities require setting a 'frame' to foreground certain aspects of practices as well as to develop a vocabulary which enables making associations between different levels of abstraction. Different practice-based approaches and methodologies put varying emphasis on different aspects of practices, practitioners, and practicing; and thus, providing a variety of 'frames' with distinct focuses and vocabularies (e.g. Schatzki 2002). Nevertheless, according to Nicolini (2012), one does not have to adopt a single, previously established, practice-based approach or methodology. Rather, certain aspects of the previously developed approaches and methodologies can be cautiously and reflectively combined to benefit from their unique strengths if they are commensurable at the philosophical level (i.e. 'toolkit' approach) (Nicolini 2012). Following Nicolini (2012), this section examines each of the research questions which governs the division of findings and analyses in Chapters 4, 5, and 6. In this respect, this section sets the shared philosophical and theoretical underpinnings of the research questions as well as their distinct focuses in exploring the activities that took place in the observed practices. Although each of the findings and analysis chapters focuses on a different set of aspects of the same practices, and are governed by different research questions (see Figure 3), the arguments presented in this section imply that the results of each chapter are commensurable, and represent self-contained, equally valid, different facets of the same organisational whole. Therefore, this section 'fine tunes' the philosophical and theoretical orientations of this research by extending the understanding of the adopted practice-based approach established so far. This further assures the rigour, and interpretability of the findings and analyses of the present study.

Research Question 1 (explored in Chapter 4): How is interdisciplinary design work accomplished in practice in BIM-enabled projects? How do people make sense of developing the design together in interdisciplinary design projects?

Implicit in the first part of this research question is the view that sees the phenomena that happen in interdisciplinary design practices as a 'work' that requires certain 'know-how' and 'effort' to be accomplished. The idea of 'spending effort' towards an 'accomplishment' connotes an 'intentionality'. The second part of the question is seeking how this intentionality enacts by asking how people make sense of working together in interdisciplinary design projects. The kind of knowing, effort, and intentionality referred in this formulation deserves further explanation to show what is aimed to be explored through this research question.

It has been shown in Chapter 2 – Literature Review that a practice-based view of knowing is 'knowing-in-action'. This suggests that the only way of knowing is situated knowing, in which knowing subject, and the object of knowledge, are continuously reconfigured based upon the particularities of ongoing situations; but there is no knowing that persists beyond practical situations.

The ultimate aim of this question then becomes the exploration of how it is possible to have any intention if there is no knowledge of what lies beyond unstable, flowing situations. More specifically, how is intentionality enacted in situations in a way that can be traced as an order that is called 'interdisciplinary design work'? Consequently, the word 'effort' here corresponds to the performances (akin to 'activities') that contribute to the actualisation of situations, knowledge, subject / object positions, and eventually intentionality in certain ways. What is 'accomplished' then is the enactment of the 'intentionality' which gives an order to the activities, and presents itself as a 'comportment' in coping with the world. A philosophical underpinning of this line of thought can be found in Heidegger's work.

Dreyfus (1993) claims that, according to Heidegger, the intentionality is not a cognitive or goal-driven orientation of a subject towards an outside and objective world, but rather one that finds its meaning in the relational whole that involves both the subject, and the external, objective world. In this view, it is the 'comportment' which refers to our directed activity (as the term has no 'mentalistic' overtones) but 'comportment', nonetheless, exhibits the logical structure of intentionality (Dreyfus 1993). Dreyfus (1993) quoting Heidegger (1982: 59) states that:

> "*Comportments have the structure of directing-oneself-toward, of being-directed-toward... [P]henomenology calls this structure intentionality*".

According to Dreyfus (1993), as part of Heidegger's phenomenological project, the intentionality here does not only denote conscious, deliberate actions, but also non-conscious, involved activity. Thus, intentionality is attributed not to consciousness but to Heidegger's concept of 'Dasein': "*the inherently social being who already operates with a pre-theoretical grasp of the a priori structures that make possible particular modes of Being*" (Wheeler 2015).

According to Heidegger, the condition of the possibility of the enactment of situated intentionality presupposes a non-intentional, or perhaps pre-intentional openness to a world as a fundamental aspect of 'being-in-the-world' (Wheeler 2015). This means that in non-deliberate activities we experience ourselves only as an absorbed responsiveness to what solicits our activity (Dreyfus 1993). Dreyfus (1993: 10-11) states that:

> "*Heidegger [claims] that such unthinking activity provides the non-salient background, both for ongoing coping and for deliberately focusing on what is unusual or difficult. The basic idea is that for a particular person to be directed toward a particular piece of equipment, whether using it, perceiving it, or whatever, there must be a correlation between that person's general skilful coping and the interconnected equipmental whole in which the thing has a place… My competence for dealing with [situations] determines both what I will cope with by using [things], and what I will cope with by ignoring [things], while being ready to use [things] should the appropriate occasion arise*".

The practical everyday orientation, the sense of familiarity that is a pre-condition of absorbed coping with the world is the condition that makes action (i.e. 'performances') possible (Dreyfus 1993), thus, enabling enactment of intentionality. According to Heidegger (1985) quoted in Dreyfus (1993):

> "*Circumspection oriented to the presence of what is of concern provides each setting-to-work, procuring, and performing with the way to work it out, the means to carry it out, the right occasion, and the appropriate time*".

To clarify this relationship between situated intentionality and absorbed coping, Dreyfus (1993) reminds Heidegger's remark on the issue:

> "*Heidegger points out that whenever we are directed towards entities by using or contemplating them, we must simultaneously be exercising a general skilled grasp of our circumstances, that opens the space that makes directed coping possible*" (Dreyfus 1993: 11).

Another way of approaching this relationship is through the term 'involvement' (Wheeler 2015). According to Wheeler (2015), Heidegger argues that a thing becomes only intelligible in relation to other related things, and it is in this sense that the involvements of both 'being' and 'things' in a relational whole determine their significance in unique situations. Wheeler

(2015) explains this through an example, and shows how significant this relationship is in understanding the 'being' in Heidegger's views:

> "*Heidegger points out that involvements are not uniform structures. Thus I am currently working with a computer (a with-which), in the practical context of my office (an in-which), in order to write this encyclopedia entry (an in-order-to), which is aimed towards presenting an introduction to Heidegger's philosophy (a towards-this), for the sake of my academic work, that is, for the sake of my being an academic (a for-the-sake-of-which). The final involvement here, the for-the-sake-of-which, is crucial, because according to Heidegger all totalities of involvements have a link of this type at their base. This forges a connection between (i) the idea that each moment in Dasein's existence constitutes a branch-point at which it chooses a way to be, and (ii) the claim that Dasein's projects and possibilities are essentially bound up with the ways in which other entities may become intelligible. This is because every for-the-sake-of-which is the base structure of an equipment-defining totality of involvements and reflects a possible way for Dasein to be (an academic, a carpenter, a parent, or whatever). Moreover, given that entities are intelligible only within contexts of activity that, so to speak, arrive with Dasein, this helps to explain Heidegger's claim… [Heidegger 1962, 16:107] …that, in encounters with entities, the world is something with which Dasein is always already familiar*".

Heidegger's overarching philosophical project is to understand 'the being' and therefore interprets human experience from that point of view. In this interpretation, there is almost a higher, pre-intentional but, nevertheless, oriented coping with the world. This is not an intentionality but rather 'circumspection' which is in correlation with all kind of competencies borne by the 'being'. A consideration of these arguments with the dimensions of knowing-in-practice presented in Table 2 (Section 2.2.2 in Chapter 2) (i.e. knowledge as material, pragmatic, situated, historical-institutional and social) reveals that these five dimensions account for both knowing-in-practice of regular activities that go unnoticed to human experience and the situation specific deliberate performances.

Based on these arguments, Research Question 1 is explored through focusing on 'the oriented and concerned nature' of observed practices. This involves 'zooming-in' to the oriented and concerned nature of the activities observed inside practices, and 'zooming-out' to the connections between various interrelated practices to put them into a wider perspective. According to Nicolini (2012), the idea of 'zooming-in' to the oriented and concerned nature of observed activities is founded on the Heideggerian view that to practice means always to care, or take care of, something (i.e. presented above as 'intentionality' / 'involvement'). Nicolini (2012: 224) further argues that:

> "*Practices are always oriented and they are performed in view of the accomplishment of the meaning and direction that they carry. For those who are involved in it, the accomplishment of a practice is experienced as being governed by a drive that is based on both the sense of what to do and what ought to be done. Zooming in would require, in this case, bringing forward and articulating the lived directionality and telos of the practice, and to appreciate the fact that such an orientation is perceived in both cognitive and moral terms… it is important to underscore that this zooming-in does not try to access the values, beliefs, or presumed inner motives which supposedly guide the conduct of the practitioners… The aim of the zooming-in is, on the contrary, to surface the practical concerns which govern and affect all participants, and a way to appreciate that from the perspective of the members, practice unfolds in terms of an often pre-verbally experienced, and yet collectively upheld, sense of 'what needs to be done'*".

According to Nicolini (2012) this kind of zooming-in is in line with the theoretical sensitivities of Schatzki's (2002) concept of 'teleo-affective structure' of practices; and Cultural Historical Activity Theory "which suggests that to understand any form of social activity, we need to foreground the object of work around which it unfolds given that it is the perceived object that bestows actions with continuity, coherence, and meaning".

On the other hand, zooming-out to higher levels of abstraction to put the lower level observations into perspective is also underpinned by Heidegger's views on 'being-in-the-world' and getting 'involved' in a relational whole. More specifically, the relational view of enacting significance and making sense of situations suggest that observed practices are connected to wider nets of practices and this wider net of practices contribute to the meaning of the situation (Gherardi 2012; Nicolini 2012). In Nicolini's (2012: 229) words:

> "*… the study of practices cannot be limited to focusing on the details of their accomplishment, and requires instead that we also strive to appreciate how the local activity is affected by other practices; how other practices are affected or constrained or enabled by the practice under consideration; and what are the material consequences of such relationships. In other words, practices can only be studied relationally, and they can only be understood as part of a nexus of*

connections. In order to understand what happens here and now we also need to understand what happens somewhere else – next door, or much further afield. Accordingly, there is a need to integrate and alternate the zooming in movement… with one which is horizon-widening and that, in accordance with the idea of zooming-in, I would describe as zooming out of the texture of practice".

This so-called 'zooming out' move aims to explore the wider relational whole in which situations are observed, and thus exploration of organisational patterns (i.e. order), or in other words the texture of practice. According to Gherardi (2012), a practice-based point of view suggests a conception of the organisation as a texture or web of practices which extend internally and externally to the organisation. Gherardi (2012: 2) states that:

"*… practices constitute a mode of ordering the flow of organizational relations. They furnish an ordering principle as the institutionalisation of activities and ways of doing which are sustained by both material and social relations. Simultaneously however this ordering principle is also temporary and unstable, and is therefore a disordering principle as well. By means of practices, organizations solve the problem of their everyday reproduction, so that practices are an answer to the problem of how to reduce uncertainty. It can also be said that they introduce indeterminacy because they always express a rationality that is contingent and in a 'becoming'*".

Consequently, undertaking a series of zooming-in (i.e. to certain aspects of the observed and reported activities in practices), and zooming-out (i.e. to higher/more-abstract levels of organisation) is argued to enable rigorous and practically relevant explanations of the studied organisational phenomena. For this reason, exploration/analysis as well as the presentation of the findings regarding Research Question 1 (and also regarding the other research questions) involve zoom-ins and zoom-outs.

Research Question 2 (explored in Chapter 5): What is the role of design artefacts in the practical accomplishment of interdisciplinary design development?

The formulation of Research Question 2 is also philosophically founded on the ideas of Heidegger introduced above, especially the idea that things become 'intelligible' only within a relational whole and their significances depend on their position in the relational whole. Design in construction is 'notional work' without any physical reference that can facilitate collective performances of people, and therefore it highly relies on design artefacts (Schmidt & Wagner 2002). As presented in Section 2.3.2.3, previous literature has shown that it is not only the representational aspects of design artefacts that contribute to the accomplishment of the organising of design work but also their performative and intermediary aspects. Based on these arguments, Research Question 2 is explored through focusing on the 'active role of design artefacts' in the accomplishment of the organising of the observed practices. This involves zooming-in to the details of the situations in which design artefacts actively contributed to the accomplishment of meaning in practices; and zooming-out to the level of interrelated practices in order to associate this with the accomplishment of project-level organising. According to Nicolini (2012), zooming-in to the active role of tools and materials is in line with a Heideggerian view of which outline is presented above. He further argues that:

> "*[When zooming-in on the active role of tools and materials] attention is… on the material... and the symbolic… tools used in accomplishing the practice. How do these artefacts contribute to the accomplishing? Are the tools and the practice actually aligned, or are there conflicts and tensions between them? How are the artefacts used in practice? In which way do they contribute to giving sense to the practice itself? What is the visible and invisible work that artefacts perform? What connection do they establish with other practices? Which type of practical concerns, or sense, do artefacts convey to the actual practising? What is the intermediation work they perform?*" (Nicolini 2012: 224).

According to Nicolini (2012) this kind of zooming-in is in line with ethnomethodology (Garfinkel 1967), and Pierre Bourdieu's (1990) and Schatzkzi's (2002) practice theories as they all suggest that "*practices have both a material and a discursive dimension, and that discursive and non-discursive aspects blend seamlessly: the saying is a way of doing as much as the doing is in what is said or not said*" (Nicolini 2012: 223).

Research Question 3 (explored in Chapter 6): How is interdisciplinary model-based working accomplished in practice? How do people make sense of interdisciplinary model-based working?

Research Question 4 (explored in Chapter 6): What are the connections between model-based working practices and other interdisciplinary efforts?

Research Question 3 (RQ 3) is formulated in the same way as RQ 1, and therefore it is underpinned by the same philosophical and theoretical assumptions as explained above. Moreover, similar to RQ 1, RQ 3 is also explored through focusing on 'the oriented and concerned nature' of the observed practices. While RQ 1 aims to explore the accomplishment of interdisciplinary design development, RQ 3 aims to explore the accomplishment of interdisciplinary model-based working, as these two were held largely separate in the observed projects. Consequently, RQ 3 particularly focuses on the 'oriented and concerned nature' of the observed interdisciplinary interactions related to model-based working. This involves zooming-in to the oriented and concerned nature of the interdisciplinary interactions related to model-based working, and zooming-out to the project-level interdisciplinary arrangements about model-based working. RQ 4 corresponds to a further zoom-out in order to put the findings of the RQ 3 into a wider perspective to explain the connection between interdisciplinary model-based working and the wider organisations of the observed projects.

3.4. The Empirical Orientation of the Study

This section starts with introducing 'ethnography' as a methodological and analytical approach to social research, alongside an explanation of its use together with the practice-based perspective adopted in the present study (Section 3.4.1). This is followed by the presentation of the details of the data collection and analysis processes of the present research in Sections 3.4.2 and 3.4.3 respectively. These are complemented with an explanation of the author's personal perception about the process of undertaking the present research and his personal profile (Section 3.4.4). Section 3.4.5 presents a reflective account of how this study deals with the inherent challenges of doing ethnographical research. Finally, the background information about the projects that were observed in this study are presented in Section 3.4.6 in order to provide the general context for the empirical findings and analyses of the study.

3.4.1. Using ethnography for a practice-based research

The investigation of practices as situated, required in-situ observation by the present researcher (Nicolini 2009; 2012). This was achieved by studying practices ethnographically (Nicolini 2009; Gherardi 2012). According to Walters (1977) developing a definition of ethnography is a challenge, "*a challenge second only to developing such a definition of culture*" (Walters 1977: 32). Nevertheless, according to Van Maanen (2011: 219) "*ethnography is first and foremost a social practice concerned with the study and representation of culture (with a distinctly small c these days). It is an interpretive craft, focused more on 'how' and 'why' than on 'how much' and 'how many'*". Cunliffe (2010) argues that "*ethnography is about understanding human experience—how a particular community lives—by studying events, language, rituals, institutions, behaviors, artifacts, and interactions*" (p. 227).

According to Cunliffe (2010) ethnographic research has a number of hallmark characteristics. First, ethnographies are about culture with a small 'c', that is, in an organisational context, they are about micro-level interactions to study meaning making of people, and/or the in-situ organising processes and commonplace practices in a specific organisation. Second, ethnographies are about context and temporality, that is, they study people in their naturally occurring settings as a means of grasping the complexity, intricacy, and mundanity (commonplace activities) of organisational life. Third, they are about sociality and the meanings enacted through it, that is, the interest is in actions, talks, symbols, texts and language of organisational members. Fourth, they are about thick descriptions and imagination, that is, the descriptive accounts provided should have an element of micro-level interactions to convey a sense of the ethnographer being there (which corresponds to 'zooming-in' in this study), and also an element of imagination that interrogates the relationship between the world and the practitioners (which corresponds to 'zooming-out' in this study). Finally, ethnographic research is about constructing tales, that is, establishing an overarching orientation for the descriptive text in which, preferably, the ethnographer acknowledges his/her role; be it a critical, confessional or any other kind of overarching orientation. Consequently, ethnography is a key focus in research for a growing number of organisation and management theorists (Brannan et al. 2007) as it allows to capture the "*emergent subtle life of organisations*" (Hodson 2001). As a result, it also enables a critical agenda for understanding contemporary ways of organising and what it means for those undertaking the work (Brannan et al. 2007). Whether the aim of ethnography should be bringing change or improvement, or should be just providing access to it, ensuring it is left intact, is an unanswered question (Brannan et al. 2007).

According to Van Maanen (2011: 218) "*ethnography is both a methodological approach to and an analytic perspective on social research*" which requires a reflection upon the pre-conceptions used in the research, and their relation to the outcomes of the research (Van der Waal 2009; Van Maanen 2011; Watson 2012). Van Maanen (2011) claims that, in organisational ethnographies, the theories and conceptualisations used in approaching the field, and in data analysis, can be plural; and it is not necessary to stake a theoretical claim on how the world is before beginning a research project. This 'theoretical cocktail', as he names it, is because there is no requirement that truths be universal or even consistent with one another. Van Maanen (2011) argues that organisational ethnography involves significant effort in developing concepts, theories, or frameworks that fit one's particular research questions and studied situations. Therefore, the ongoing relation of the ethnographer and the theory is founded on wider social theory but depends on the taste of the ethnographer and fitness to data (Van Maanen 2011). Similarly, Jordan (1996) emphasises that, in ethnography, the same practices can be viewed and explained in different ways by arguing that a distinction can be made between two kinds of data collected; i) data collected in categories relevant to participants (i.e. 'emic data') and ii) data collected from an outsider perspective ('etic data'). According to Jordan (1996) it is important to be aware of this distinction and aim to collect 'emic data'. Nevertheless, she argues that this does not mean that the emic data should be presented as it is, because there is no unitary outside view; and therefore, the collected 'emic data' needs to be translated into an ethnographic text considering the audience of the research (Jordan 1996).

The 'theory' adopted in the present research is not 'a theory' in its general sense; that it is not "*a formal system of hypotheses that generate explanations and predictions*" (Stern 2003: 187). Therefore, the practice-based view adopted in the present research provides a theoretical orientation in the sense that it provides a systematic way of approaching the relationships between the actions people take and the structures of organisational life (Stern 2003; Feldman & Orlikowski 2011). Therefore, the use of 'practice theory' in this research can be argued to satisfy the need to found the ethnographic research on social theory as stated by Van Maanen (2011). This foundation guides where and what to look at (see Section 3.3.2 in this chapter) but doesn't tell what should be expected to be seen, or how to understand it (i.e. it does not provide predictions). Such an approach allows a variety of 'theories' to be considered to appreciate their distinct contributions in understanding the phenomena of interest. During this research, in line with Van Maanen (2011), the present researcher went through an iterative process in which his focus continuously moved between his object of study and the literature about organisational studies, design studies, and technology studies. In this respect, the third and fourth sections of Chapter 2 – Literature Review (i.e. Sections 2.3 and 2.4), included studies that adopted various theoretical approaches. As stated above, 'ethnography' allows and values this 'theoretical cocktail' as all different theoretical approaches have some validity in the observed practices, and thus, can contribute to the empirical orientation of the researcher.

In this respect, the data collected in the present study is the result of continuously switching between insider (i.e. emic) and outsider (i.e. etic) perspectives. The researcher developed an insider perspective based on i) his passive observation of practices as well as communications in the studied projects for extended periods of time, and ii) his past professional experience of working in similar settings. The researcher also developed several outsider perspectives on the direct observations from the field by concurrently and repeatedly revisiting literature, attending academic conferences, and professional events. These 'insider' and 'outsider' perspectives were switched iteratively on an ongoing basis during the process of data collection. Consequently, the resulting empirical data is an outcome of this continuous switching as encouraged by the ethnographical approach. This can be summarised as a series of inductive and deductive reasoning that occurred as result of i) 'zooming-in' to unique situations, and 'zooming-out' to patterns of performances, communications, and representations at project- and wider-level(s) organising; ii) the researcher's own empirical experience in the field of study; iii) the researcher's changing theoretical knowledge about social theory, and studies on design and technology; and iv) analytical and linguistic challenges experienced in writing about the rich, empirical findings of the fieldwork in the academic papers that were developed during the data collection period.

3.4.2. Data collection

In this section, the data collection methods that were employed, and the details of the collected data are presented. According to Jordan (1996) workplace studies draw heavily on participant observation, in-situ question asking, and micro-analytic methods of analysis, which she refers to as 'ethnographic methods', more as a convenient shorthand than as a claim to purity, comprehensiveness, or exhaustiveness of the studies. Jordan (1996) claims that these are methods that grew out of anthropological ethnography on the one hand, and ethnomethodology on the other (see Pollner & Emerson 2007 for a discussion of the relationship between these two areas of study).

The present research has used both (passive) participant observation, and formal/informal communications for data collection at three ongoing organisational 'sites' (Schatzki 2002), in which the people who were observed had already started to interact to deliver the projects. These projects were i) an educational building project in its detailed design stage – the EduBuild project; ii) an office building project in its conceptual/design development stage – the OffiBuild project; and iii) a high-technology (and high-precision) equipment manufacturing laboratory in its detailed design stage – the LabBuild project (see Section 3.4.6 in this chapter for background information). The main criterion for choosing the projects was their use of coordinated information models. This means that in all the studied projects, information models were developed and used by more than one discipline in the design team, and therefore needed interdisciplinary coordination. The number of the studied projects, and the length of the observation periods were determined by the resource restrictions.

Table 4 below shows the details of the collected empirical data. As shown in Table 4, during the ethnographic field research, the interviews were only conducted with the members of the design team of the EduBuild project. This is because the EduBuild project was the most ambitious in terms of its BIM use, and the researcher needed to investigate the in-discipline modelling practices in-depth, in order to better understand the organisation of interdisciplinary model-based working. In the two other projects, the observed interactions and informal communications were enough to capture the interdisciplinary model-based working, and therefore, no interviews were conducted.

	Passive and interrupted observation	**Interviews (recorded and transcribed)**	**Informal communications**
Preliminary research	N/A	Seven interviews were conducted about the changes in the professional practices driven by the use of BIM technologies. These were conducted with professionals from various backgrounds (see Appendix 1 for the interview questions).	N/A
EduBuild project	23 meetings (each 1 - 1.5 hours) were observed over a period of ten months (design coordination meetings; one-off design coordination workshops; clash detection and model coordination meetings). Audio and video recordings were not allowed. The design artefacts brought to the meetings were observed, and copied when it was possible and allowed.	Five interviews about the modelling approaches of different members of the design team were conducted.	- Conversations before, and after the observed meetings; - After work pub drinks.

OffiBuild project	21 meetings (each 2-3.5 hours) were observed over a period of ten months (design coordination meetings which also involved model related discussions). Audio and video recordings were not allowed. The design artefacts brought to the meetings were observed, and copied when it was possible and allowed.	N/A	- Conversations before and after the observed meetings.
LabBuild project	6 meetings (each between 1-2 hours) were observed over a period of three months (both design development, and model related meetings). Audio and video recordings were not allowed. The design artefacts brought to the meetings were observed.	N/A	- Conversations before and after the observed meetings; - Two site visits with the representatives of the main contractor, client, and mechanical and electrical engineering sub-contractor; - Lunch time conversations with the representatives of the main contractor, architect, and clean rooms sub-contractor.

Table 4 - Details of the collected empirical data

In terms of observations, the researcher did not spend all the time on the field for a given period but his participation was rather interrupted, and did not involve all interdisciplinary practices in the observed sites. The 'passive' and 'interrupted' character of the observations can be justified through the following arguments. First, the aim was to research the 'working together' of various practitioners from various disciplines through the conducted ethnographic fieldwork. The culture of 'working together', which was the concern of the conducted ethnographic fieldwork, was established and maintained by the practitioners through interrupted interdisciplinary interactions. Therefore, the 'interrupted' character of interactions were part of the natural setting of inquiry. Besides, the researcher had previous professional working experience in various design teams, and therefore had already been familiar with interdisciplinary design practice in construction at the time of observations. These two points constitute the first argument for the justification of the interrupted observation of the studied projects. Second, the data collection, analysis, and text of this research are in line with 'ethnomethodological ethnography' which aims to reveal the ways practitioners make sense of their work by focusing on activities and interactions. According to Gubrium and Holstein (1997) this is different than traditional ethnography which aims to present the world from the practitioners' eyes. In ethnomethodological research, the researcher seeks to maintain a distance from the practitioners' world (Schutt 2011) (see the next section for a more detailed explanation of ethnomethodological research and analysis). This provides another argument for the justification of both the 'interrupted' and 'passive' characters of the observations (a more detailed account of the reflections of the researcher upon the challenges of conducting ethnography can be found in Section 3.4.5 in this chapter).

The observations of the EduBuild and OffiBuild projects spread over long periods of time (i.e. ten months each). Although only six meetings were observed in the LabBuild project, the relevance and accountability of the findings from the LabBuild project can be justified considering the 'interactional expertise' (Langley et al. 2013) already gained by the time the direct observations of the LabBuild project began. According to Langley et al. (2013) one important reason to conduct longitudinal studies when a process ontology is adopted, is to enable the researcher to develop 'interactional expertise', the kind of knowledge required to communicate without necessarily being able to practice in the domain. Considering that the researcher had previous professional experience in the field, and he had been observing the Edubuild project for eight months, and the OffiBuild project for five months when he started to observe the LabBuild project, it can be argued that the researcher had already developed interactional expertise when he started to observe the LabBuild project. The timeline of the data collection of this research is illustrated in Figure 4.

Observation of two of the studied projects for long periods (i.e. ten months each) also enabled what Langley et al. (2013) calls 'temporal observations'. According to Langley et al. (2013), longitudinal research design in studies that adopt a process ontology enables

> "*researchers to examine the recurrence and accumulation of progressions. This permits replicating theoretical ideas in successive time periods and also to analyzing how the changing context from previous periods impacts subsequent events in current periods*" (Langley et al. 2013: 7).

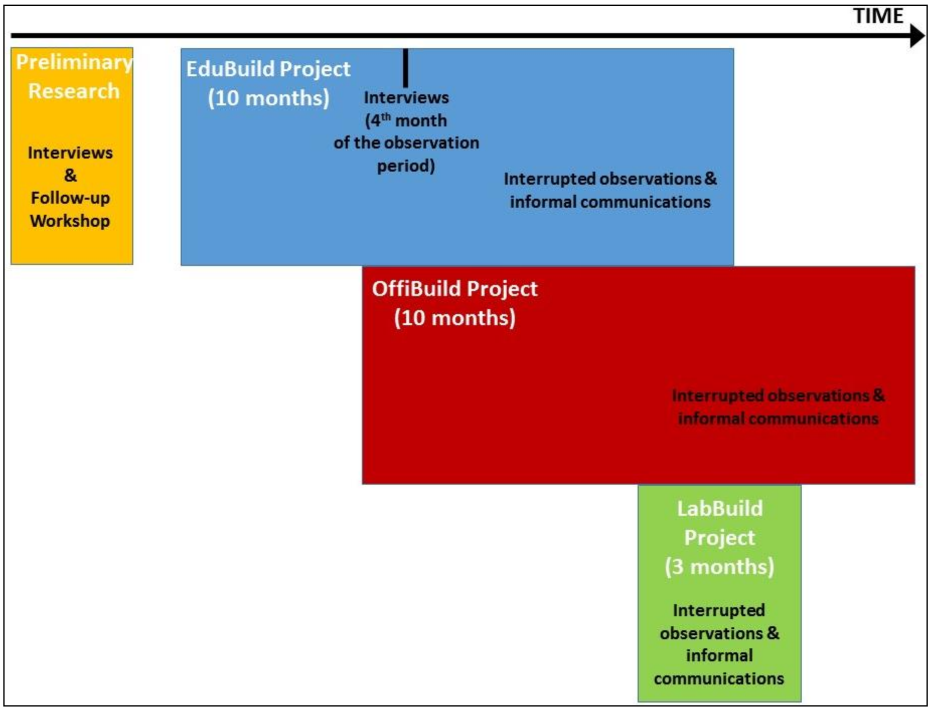

Figure 4 - Timeline of data collection

This was important to be captured in establishing the evolving aspects of the ways practitioners made sense of interdisciplinary design work. The researcher witnessed the changing expectations and perspectives of the practitioners along the developing design in the EduBuild and OffiBuild projects. Moreover, all the observed design practices were at different stages of development with some overlapping temporal and scope aspects. The variety of the observed design stages in different sites facilitated cross-case speculations about how and why design stages might or might not enact similar, or different, meanings and perspectives in different projects.

Furthermore, the design of data collection in this research considered the validity and credibility of the arguments by studying multiple sites. The study of multiple sites enables cross-case replication, and thus, allowing theoretical ideas to be tested and deepened in different settings (Langley et al. 2013), thus, giving more credibility to the argument put forward in the study.

Another aspect about observations that deserves further explanation is how the researcher directed his attention at real time in practices as a passive observant. Sandberg and Tsoukas (2011) provide an account of 'practical rationality' and also directions to theorise in practice-based studies based on Heidegger's philosophy. Sandberg and Tsoukas (2011) suggest focusing on two main phenomena for developing theory that reflects 'practical rationality'. The first is concerned with what they call 'entwinement as the logic of practice' (Sandberg &

Tsoukas 2011) which refers to the idea that "*we are never separated but always already entwined with others and things in specific sociomaterial practice worlds"* (Sandberg & Tsoukas 2011: 343). They state that:

> "*Taking entwinement as the logic of practice highlights that the identity of a particular sociomaterial practice is non-contingent in the sense that it incorporates distinctions that provide its practitioners with a certain orientation, without which the particular practice would not be what it is (Taylor, 1985a: 23, 1985b: 36). Saying that practitioners are non-contingently related to their practices does not tell us anything about how they are related; existential non-contingency does not preclude historical contingency—far from it"* (Sandberg & Tsoukas: 343).

Therefore, according to Sandberg and Tsoukas (2011) one of the two main ways of observing practices in order to develop theories about them is to seek particularities and patterns of this entwinement, including embodiments and temporality of practices.

The second is concerned with what Sandberg and Tsoukas (2011) call "*revealing the logic of practice through temporary breakdown*". They explain the idea of paying attention to breakdowns to understand the practice in the following passage:

> "*Practitioners' primary mode of engagement in a sociomaterial practice is absorbed coping— dealing with the world non-deliberately. When their absorbed coping is significantly disrupted, practitioners shift to [a mode] … characterized… by the subject-object relation. When the disturbance is a temporary breakdown, practitioners shift to the involved thematic deliberation mode: their relational whole comes into view and they pay deliberate attention to what they do, while still remaining practically involved in the task at hand. In other words, it is in the mode of involved thematic deliberation where the logic of practice momentarily becomes manifest and illuminated*" (Sandberg & Tsoukas 2011: 345-346).

In relation to this line of thinking, attention was paid in particular to how recurring aspects of the observed practices are re-produced as well as how temporary breakdowns are noticed, evaluated and solved. This aspect is evident in the way data is analysed and presented, for example, some breakdowns are stated as 'events' in the presentation of findings. The noticed and noted events of entwinement and temporary breakdowns during the observations were brought up through informal communications that were held with the practitioners right after the observed meetings, or short after them for enabling their correct interpretations by the researcher.

The observational data were recorded in the field notes and the reflections on these were supported by the interviews and informal communications as explained above. The researcher did not have any format for the recording of the observations as field notes in his notebook. The researcher took field notes as bullet points when he thought he noticed a pattern of entwinement, a temporary breakdown, or a particular symbolic meaning that was alien to the researcher but familiar to the practitioners. These notes involved both descriptions of the noticed events, and researcher's self-reflections about what he thought happened. Occasionally, the self-reflections of the researcher about what happened also involved some concepts or notions that the researcher learned through literature review, and thought might be relevant to a particular observation. These self-reflections about the observations helped the researcher in going back in time during the subsequent stages of the data analysis as they reminded the explanation attached to a particular event in-situ in addition to its description.

3.4.3. Data analysis

The overall tone of the data analysis in the present research comes close to 'ethnomethodological analysis' (Schutt 2011; Gherardi 2012; Nicolini 2012). As briefly mentioned in the previous section, this means that the analyses aim to reveal the ways practitioners make sense of their work by focusing on activities and interactions. According to Gubrium and Holstein (1997) this is unlike the naturalistic orientation of traditional ethnography which is based on providing representational ('scenic') features of everyday life.

> "*… the ethnomethodological analyst seeks to maintain some distance from… [the practitioners'] world. The ethnomethodologist views a code of conduct… not as a description of a real normative force that constrains social action, but as the way that people in the setting create a sense of order and social structure (Gubrium & Holstein 1997: 44–45). The ethnomethodologist focuses on how reality is constructed, not on what it is*" (Schutt 2011: 336).

Therefore, the ethnographic texts provided in this research, which are at the centre of the analyses, carry traces of ethnomethodological research in the sense that:

> "*the focus shifts from the scenic features of everyday life onto the ways through which the world comes to be experienced as real, concrete, factual, and 'out there'. An interest in members' methods of constituting their world supersedes the*

naturalistic project of -describing members' worlds as they know them" (Gubrium & Holstein 1997: 41).

However, this research diverges from ethnomethodological tradition in the purposes of its analyses. Specifically, although Shapiro (1994) claims that the agenda of 'ethnomethodological ethnography' is rigorously descriptive rather than theoretical or explanatory, the present research poses ethnomethodological questions on its ethnographic data in order to provide explanations and to theorise. This is based upon Nicolini's (2012) insight about adopting a 'toolkit approach' to practice-based studies, which corresponds to combining the strengths of various practice-based theories and methodologies through a reflective exercise (see Sections 3.3.1 and 3.3.2 in this chapter).

The process of the analysis of data in the present research is close to that of 'grounded theory development' as explained in Schutt (2011) and Gioia et al. (2013), but with a few differences. The identified research challenge (i.e. the need for practically relevant conceptualisations of interdisciplinary design in BIM-enabled construction projects), and the practice-based roots of it, gave direction for attention at the observed meetings, and content of formal/informal communications as explained above. Consequently, the collected data was unstructured but aligned with the focus on 'patterns of entwinement' and 'breakdowns'. Meanwhile, constantly revisiting literature with a view to finding conceptual and theoretical fixes between the literature (e.g. 'sensemaking' - Weick 1995; 'sociomateriality' - Orlikowski 2007) and the empirical data was a key component of the study. These theoretical constructs certainly affected the nature of the in-situ studies and the desk inquiry, but in a way which increased the need to look closer at certain aspects of data and practice, rather than adopting fixed conceptual categories to be filled with data. In this regard, the data analysis and data collection went hand in hand, and the theory development was progressive, similar to grounded theory development explained in Gioia et al. (2013).

Once the data collection phase ended, all the available data were reviewed twice and explanations that had started to bridge the activities in the observed practices and the organisational structures were refined around overarching, dynamic concepts. This was a process in which a longitudinal perspective on the EduBuild and OffiBuild projects was combined with a cross-case comparison that also included the LabBuild project to refine the concepts. When the writing-up process started, further refinement was required to encompass the richness of the data. The four Research Questions, reflecting the researcher's evolving frame of inquiry in data collection/analysis were devised (see also Section 3.3.2 in this chapter). This final round of refinement also required the labelling of various interrelated levels of organising (i.e. levels of abstraction) in order to guide the reader and to provide high-level explanations (i.e. what were observed when 'zoomed-out') through their associations with practice-level findings (i.e. what were observed when 'zoomed-in') (see Sections 3.3.1 and 3.3.2 in this chapter for more information about how the present study uses 'zooming-in' and 'zooming-out' as methodological devices).

In summary, for this study, data analysis has been progressive and spread over three main steps. The first took place along the data collection during which the main explanatory organisational concepts emerged. The second step involved desk analysis of the findings in order to refine these concepts. The third step involved adoption of an analytical structure to develop the concepts in a way that reflected i) the evolving frame of inquiry of the researcher during the fieldwork; and ii) the principal argument that is put forward in the study (see also Sections 3.3.2 and 3.4.5 in this chapter).

3.4.4. Personal perception of the research process, and personal profile

This section presents self-reflection of the researcher on the research process, followed by an overview of his personal profile. These are required to be provided because the researcher has been the main research instrument for the present study. Consequently, an overview of the process of the research from his eyes as well as an overview of his personal profile are needed to enable a better interpretation of the study.

Personal perception of the research process

The initial aim of this doctoral research project, as advertised by Birmingham City University, was to explore organisational integration in BIM-enabled projects. As soon as I started my research, my director of studies directed me towards reading the literature that is critical of the widely-promoted benefits of contemporary information and communication technologies (ICT). Therefore, I started my research journey with developing a critical view on ICT, which questions capabilities of ICT 'in the wild' (i.e. in practice). Prior to my doctoral research journey, I had not had any interest in, or knowledge about the critical studies about the use of ICT but it did not take me long to understand what they were about due to my personal negative experiences with ICT use in organisations.

Before I started this research, I worked in multi-national contracting and design consultancy companies in which company-wide ICT were in place but used in very limited ways. Although I spent most of my time in front of my computer in my previous jobs, the amount of the meetings that I attended and the contributions of my personal relationships with colleagues to 'get things done' were significant. Therefore, as soon as I started reading the literature which criticises the over reliance on the ICT, or which points to its limited and appropriated uses in organisational practices, I could relate what I read to my own previous experiences.

This initial period of literature review, which focused on the studies that are critical about the widely-promoted benefits of ICT, allowed me to realise the extent of the problem with embedding ICT in all aspects of organisational life based upon a pure techno-optimism. During this period, I familiarised myself with the ongoing methodological debates in the field of ICT and organising, and social theories that provide explanations about organising. I remember being surprised with the limited number of empirical studies that had attempted to critically approach the widely-promoted benefits of ICT in domain specific research such as research in Building Information Modelling (BIM) in construction. Following the extensive review of the studies which approach critically to ICT in organising, I realised that I equally needed to develop a solid understanding of technology upon which BIM was built. Therefore, I went through another round of literature review which covered the studies which focus on the technological capabilities of ICT and their potential benefits, including how databases and models work, how the technological aspects of interoperability work, and how ICT use had evolved in construction.

Following this initial period of extensive literature review, I conducted a preliminary research (summarised in Section 1.2 in Chapter 1). I formulated the interview questions for the preliminary research with the purpose of finding out how people feel about and handle the changes that had occurred in their jobs due to BIM implementation, and how the promoted technological capabilities of BIM were used in their practices (see Appendix 1 for the interview questions used for the preliminary research). The results of this preliminary research revealed that the uses of BIM technologies were different from one discipline to another and from one project to another even in the same company. The results of the preliminary research, together with the background that I developed through literature review, led me to conduct an ethnographic fieldwork to explore how all the inherent variety in construction design projects (e.g. different design disciplines, different design teams, different project-specific requirements etc.) were managed to be organised as meaningful practices, and the role of BIM in this. Therefore, I started observing and inquiring into interdisciplinary interactions in ongoing BIM-enabled construction design projects.

At the beginning of the ethnographic fieldwork, one thing that I found particularly difficult was to keep myself continuously focused on the ongoing real-time interactions as a passive observer, and simultaneously trying to make sense of them as a researcher. Consequently, I needed to adopt and continuously remind myself some principles for the real-time observation and recording of practices in my field notes (see Section 3.4.2 in this chapter). At the early stages of the fieldwork, while I was still in the process of learning how to manage my attention real-time during the practices that I observed, I had already started to have some important revelations about model-development and design-development. My first major revelation enabled by the fieldwork was that model development was largely kept separate from interactions related to design development. Besides, model development required additional structures, conventions and ongoing discussions to keep the models as legitimate and accountable sources of information for the changing needs of multiple parties (see Çıdık et al. 2014 – Paper 3 in Appendix 3). Over the course of the fieldwork, this kind of major as well as the aggregation of a number of relatively minor revelations related to the practicalities of developing design and model-based working, played significant roles in the evolution of my frame of inquiry. During the data collection stage (i.e. the ethnographic fieldwork), the findings themselves and the meetings with my supervision team about the findings enabled me to progressively shift my focus to certain aspects of practices that seemed to be essential in explaining the organisation of design work and model-based working. Nevertheless, it is important to emphasise that I had never developed a strict or rigid structure for data collection during the ethnographic fieldwork as I wanted to always remain open to any new ideas and surprises.

Meanwhile, trying to write academic papers based on the growing findings of my fieldwork made me better understand why methodology is a big issue that needs to be dealt with care to make explanations about the relationship between people and ICT in practice. This led me to read more on practice-based studies which seemed to be able to capture the richness in practices while still being able to provide valid conceptualisations and explanations about organisational phenomena. I read about philosophical, theoretical, and empirical aspects and sensitivities of practice-based studies which allowed me to develop a sound understanding of practice thinking. In parallel with this, I have also kept reviewing the literature on organisational studies, design studies, and technology studies.

At the end of the fieldwork I could intuitively know and talk about the main phenomena that I wanted to highlight in this study, and the three main concepts that I would like use in explaining them (see Chapters 4, 5, and 6). However, as my approach to data collection was very unstructured I needed to go through the data that I collected several more times and complete two consecutive rounds of review of all the data available. This exercise was mainly a desk analysis of the collected material which included a high number of iterations to clarify the main concepts that emerged from my findings to myself. This meant spending an extended reflective period of two months to establish how these concepts were different and interrelated at the same time.

Following this stage, I first started by writing a draft of the discussion chapter of my thesis which made me realise the difficulties of writing about and theorising through practice-based, rich, empirical data. My initial plan was to have one findings and analysis chapter, and one discussion chapter within which I would develop and discuss the three main concepts that emerged from the fieldwork. However, I learned by experimenting that this was inadequate because the three main organisational concepts were highlighting different facets of the same organisational practices, and therefore using a single, continuous narrative to substantiate and develop all three concepts was problematic in this case. At my second attempt, I planned to write the findings of the fieldwork as three separate case studies for the three projects that I observed, and then to develop the three main concepts in the following concept development chapter. According to this plan, the concept development chapter would be followed by a discussion chapter. However, I again learned by experimenting that this also was inadequate because keeping the practice-based empirical findings and concept development separate (i.e. largely disconnected) created serious problems in communicating which part of the presented empirical findings indeed supported which of the three main concepts and how. After my second unsatisfactory attempt in writing-up the thesis, I had an extended period of reflection about how to structure the thesis which lasted around two months. During this period, I frequently re-visited the empirical data that I had, and the literature on practice-based research, to develop a structure that could effectively communicate findings, analyses, concepts, and discussion. At the end of this reflective period, I came up with the current structure of the thesis which presents three findings and analysis chapters to develop the three main concepts that emerged from the fieldwork. According to this structure, there are different research questions set to be addressed in the three findings and analysis chapters (see Section 1.2 in Chapter 1). These research questions enable different empirical foci for each of the findings and analysis chapters, and thus enabling the use of different narratives (i.e. 'frames' as called in Section 3.3 in this chapter) in developing the three main concepts (see Section 3.3 in this chapter). Through these three narratives a better connection between the practice-level empirical findings and the three main concepts become enabled. Further, setting separate research questions to be addressed for each of the findings and analysis chapters also enables overall better communication of the research as a journey because I set the research questions in such a way that they also reflect the evolution of my frame of inquiry during the fieldwork (see Figure 3 in this chapter, and Section 4.6 in Chapter 4).

Nicolini's (2012) insight on adopting a 'toolkit' approach to combine the strengths of various practice-based approaches and methodologies, as well as his 'zooming-in' and 'zooming-out' metaphors inspired me in developing the methodology that I adopted in this study. During the reflective period that I spent after my second unsuccessful attempt of writing-up, I spent considerable amount of time to excel in practice-based approaches including their philosophical roots and evolution; and therefore, I became confident about going on with a reflective combined use of them as suggested by Nicolini (2012). The two kinds of empirical focus that I adopted (i.e. 'focusing on the oriented and concerned nature of practices' in Chapters 4 and 6; and 'focusing on the active role of tools and materials in practices' in Chapter 5) were developed in Nicolini (2012) as different possible ways of studying practices. The innovation I made was to combine different foci in the same study, and use them in focusing on different aspects of the same organisational phenomenon to provide equally valid, self-contained, but nevertheless interrelated explanations of the studied organisational phenomena.

Such an innovation also enabled me to explicitly introduce the aspect of exploring 'order' in BIM-enabled interdisciplinary design projects, which was already implicit in the findings and initial conceptualisations. The methodology used in this study allows the juxtaposition of different explanations of 'organising' of the same empirical phenomena, and thus, enabling an understanding of 'order' that accounts for all these different explanations. This implies that all different explanations about 'organising' that are made in the present study are equally present and valid (i.e. because they emerge from the same set of data), and that in practice all the explained organisational phenomena interact with each other in producing certain organisational structures and order.

Once I developed this methodological perspective, it was almost indispensable to use the emerging practice-based understandings of 'organising' and 'order' in BIM-enabled design projects to discuss the main relevant constructs of design (in construction), design collaboration (in construction), ICT (in construction design), and hence ICT-driven change in construction design. It is through these discussions that this study could deliver wider impact and enable original ways of thinking about design, design collaboration, ICT use in design, and therefore ICT-driven change in construction design. In conclusion, I believe that the thesis you are holding in your hands has been loyal to its aim in providing alternative views of design, design collaboration, and ICT (use in construction design), and hence, contributing to enabling a different 'order' in which the 'realities' of practices are better acknowledged and addressed.

Personal profile of the researcher

As stated earlier, an ethnographic approach to research sees the researcher as an autobiographer, and thus, providing some personal information about the author is essential to facilitate the interpretation of the research. Here, following Uusitalo (2015), I will briefly outline four aspects of my life which are my life course, personality, education / being a researcher, and work history.

Life course: I am a man in his thirties with an educational background to M.Sc. level. I completed my M.Sc. study four years before I started this research project. During the time between the completion of my M.Sc. study and the start of this doctoral research I have travelled, worked and lived in four different countries on three different continents. Therefore, when I started this research, I had already had experience in entering and learning about new cultural environments which made it easier for me to conduct an ethnographic fieldwork. Although prior to this doctoral research I lived in the UK for one year in total, when I was offered a full-scholarship for this doctoral research four years ago, I was not located in the UK. I believe that this is an important point because not having many friends around allowed me to spare long hours for this research. In general, I can say that I started this doctoral research at some point in my life when I felt bored and unproductive about the corporate life that I had been going through. I wanted to do something else with my time which would be more valuable for myself and for society. Consequently, for me, starting this research was not a continuation of an ongoing educational journey. Neither was it the result of a specific career driven interest. When I started this research, there were two main things that I knew I wanted to achieve. First, I wanted to learn more, and make the most out of my doctoral study as a personal development journey. Second, I wanted to deliver a work that could benefit large audiences instead of small privileged groups such as business owners or software vendors.

Personality: I am an open and sociable person, which allowed me to rather easily communicate with the practitioners in different settings. I don't easily jump on conclusions in my judgements and generally stay away from conclusive opinions. This indeed implied a challenge for this study as I kept the data-collection unstructured and open to surprises until the very last moment. On the one hand, this increased the richness of the research, but on the other hand, it resulted in extended desk analysis and writing-up process to pull the ideas and findings together to develop arguments that are understandable for the reader as well as reflecting the contingent nature of the observed practices.

Education / being a researcher: I hold a B.Sc. (Hons) in Civil Engineering, and an M.Sc. in Project and Construction Management from Istanbul Technical University, Turkey. My M.Sc. thesis focused on establishing the information management problems in the Turkish construction industry supply chain, and provided propositions on how these problems should be approached with a consideration of the capabilities of contemporary ICT. However, doing a Ph.D. in the UK was very different than my previous educational experiences. First, I was not familiar with the UK higher education system. Second, doing Ph.D. was a very lonely process in which even my supervisory team could provide limited help, and direction. Now I realise that it was partly because of my incapability of communicating the complex ideas and arguments that I had in my mind to others which left me helpless when I got lost inside my data or in the middle of mountains of literature. Therefore, my learning experience during this doctoral research has been almost painful, and required a never-ending determination and emotional stability. Consequently, this thesis is the result of an ongoing effort of reading, writing, and re-writing until the argument I wanted to put forward was as clear and rich as I and my director of studies would like it to be.

Work history: I have six years of experience in professional practice which mainly involved design engineer, assistant project manager, and business development and bidding engineer roles. I worked in the UK, Algeria, Morocco, and Turkey prior to the start of this study and most of the professional roles that I undertook in these countries were with multi-national companies. Therefore, before I started this research, I had experience and knowledge about the design and construction processes, and how these could change from one country to another. This helped me to relate to practitioners relatively faster as I already had an understanding of the institutional and professional standards of practices followed in construction projects. Although the practices that I observed attracted my professional attention in terms of the design issues that needed to be resolved, I have always felt confident about keeping my 'researcher hat' on, rather than wearing my 'designer hat'. Consequently, I believe that my professional experience in the domain had more of an enabling effect rather than a disruptive one as I was a passive observer for most of the data collection period.

3.4.5. A reflection upon the inherent challenges of doing ethnographic research

Literature on ethnographic research establishes several challenges associated with conducting ethnography and defining its success criteria. This section discusses the present research in terms of the three main challenges of ethnographic research identified by Humphreys et al. (2003). According to Humphreys et al. (2003: 6), there are many ways of doing ethnography but there are three central challenges that ethnographers face: i) how to handle the delicate balance between the self and the other in fieldwork and writing; ii) how to engage in the everyday life of the culture being studied; and iii) what criteria to apply in judging the quality of ethnographic research.

Concerning the first point, in line with Van Maanen (2011), Humphreys et al. (2003) claim that the ethnographer is indeed an autobiographer because studying the 'other' involves and requires a search and a construction of the 'self'. Therefore, the 'self' is unavoidably projected on the data collection, data analysis, and in the writing-up process to varying extents. According to Humphreys et al. (2003) this can range from distancing the 'self' from the 'other' as much as possible and 'interpreting' the observations, to making the ethnography a 'personal story' meshed with interactions of self and others around. When this point is considered together with Cunliffe's (2010) argument that "*ethnography is about understanding human experience*" (p. 227), it can be claimed that, for organisational ethnography, bringing the experiences of an ethnographer's 'self' and the observed 'other' as close as possible, is a key consideration in justifying the distance between 'self' and 'other'. Therefore, a reflection upon the interactional experiences of the observed practitioners can provide justifications about the present research's approach to ethnography in terms of handling the balance between the 'self' and the 'other' in fieldwork and writing.

In this research, the focus of the ethnographic fieldwork has been on exploring interdisciplinary organisation of BIM-enabled construction design. Interdisciplinary organisation of BIM-enabled construction design was based on interrupted encounter of practitioners who strongly held to their different professional identities (i.e. architects, engineers etc.). Therefore, it can be argued that, during the fieldwork, the ethnographer's experience about the observed practices has come closer to those of the practitioners by observing only the interdisciplinary interactions which were held on an interrupted basis. Consequently, it can be further argued that the challenges of the ethnographer about i) developing 'interactional expertise' (Langley et al. 2013 – see Section 3.4.2 in this chapter); ii) temporary breakdowns in his 'interactional expertise'; and iii) constructing identities of the 'self' and 'other' due to his interrupted involvement; were indeed challenges that were present also for the observed practitioners. Hence, it can be concluded that, in the particular case of the present study, interrupted involvement of the ethnographer, which created an unavoidable distance between the ethnographer's 'self' and the observed 'other' during the fieldwork, was indeed appropriate and brought the researcher's experience closer to those of the observed practitioners.

The explanation provided above can be extended by also considering the difference between the amounts of the time that the observed practitioners spent on their discipline-specific activities, and interdisciplinary activities. The amount of the time spent by the practitioners in their own discipline-specific offices and activities was much more than the amount of the time that they spent in the observed interdisciplinary encounters. In this sense, it seemed that none of the participants of the observed practices would make these interdisciplinary encounters as a central part of his/her personal story in the project. Consequently, this further provides an explanation of the distance between the 'self' and the 'other' during the fieldwork, and an explanation of why it would not be appropriate to write-up the results of this ethnographic study as a personal story.

A final point about the position of the 'self' and the 'other' in the present study is related to the analytical preferences made herein. The analyses of the present research come close to 'ethnomethodological analysis' in which the researcher seeks to maintain a distance from the practitioners' world (Schutt 2011) in establishing practitioners' *"… methods of constituting their world …"* rather than *"… describing members' worlds as they know them*" (Gubrium & Holstein 1997: 41) (see Section 3.4.3 in this chapter). This provides a further justification about the distance between the 'self' and the 'other' in the present research.

Humphrey et al.'s (2003) second point is about how to engage in the everyday life of the culture being studied. Concerning this point, the explanations and reflections are already provided regarding which principles and kinds of events guided the researcher in directing his attention real-time during the observations (see Section 3.4.2), and over the course of the ethnographic fieldwork (see Sections 3.4.2, 3.4.3, and 3.4.4 in this chapter). Therefore, no further explanations will be made here.

Humphrey et al.'s (2003) third point is about the criteria in judging the quality of ethnographic research. Concerning this point Humphreys et al. (2003) claim that the quality of an ethnography should not be based on logic or reason but on aesthetical judgements. According to this view, the evaluative criteria of ethnography should not be based on any pre-made frame, and the evaluation should be made on the basis of individual ethnographies. Humphreys et al. (2003: 19) states that:

> "*… ethnography works best when it surprises us, when it overturns preconceived notions or exposes the limits of our prior understanding. So … any previously defined criteria are likely to discourage good ethnography rather than encourage it. What is needed is the capacity to (re)formulate criteria in the moment of relating to a given piece of work*".

Nevertheless, Humphreys et al. (2003) also make the point that the textual account need to be able to deliver a harmony as a whole, without the requirement that what is produced be purely harmonious. This supports Butler (1997: 928) cited in Humphreys et al. (2003):

> "*[the aim of ethnography is] to draw an audience into a collective experience - in which a version of the true is demonstrated for that collective to judge*".

The idea of 'harmony of the whole' in judging the quality of an ethnography is also in line with Cunliffe (2010) who argues for an overall orientation of the constructed tale.

The narratives provided in the findings and analysis chapters (see Chapters 4, 5, and 6) deliver harmony as a whole, and thus enabling overarching orientations in the ethnographic texts of the present research (Cunliffe 2010), while also considering and building upon the non-harmonious, clashing or conflicting activities and stances inherent in the observed interdisciplinary practices. Considering Van Maanen's (1988) categorisation of ethnographic writing, these narratives are close to what he calls 'impressionist tales', which aim to foreground the interpretive and socially constructed nature of practices in the interactions of the practitioners. To achieve this, each of the findings and analysis chapters of the present research provides 'living stories' (Boje 2011) of the observed projects to highlight different sets of aspects of practices that contributed to the interpretation and social construction of the practitioners. According to Boje (2011) 'living stories' are without beginning and ending; they are about movement and establishing foundations for further story spaces, thus enabling the inclusion of 'little wows' which are generally erased in monolithic narratives. In this research, the living stories are meshed with so called 'events' in which either the 'little wows' or the practical examples of the 'impression' driving the living story are exemplified with a style that comes closer to the lived situation. Enabling multiple stories through a mix of the guiding, impressionist living story, and several 'events', is argued to reflect both the polyphony inherent in the observed practices and the harmony that is expected from a good ethnography.

3.4.6. General overviews of the studied projects

In this section background information regarding the studied projects and the extent of the researcher's observations in each project are presented to provide the general context for the empirical findings and analyses of the study.

The EduBuild project

This was an educational building construction project. The project, which was widely called as 'Phase 2' among the members of the design team, was the second phase of an educational campus development in the United Kingdom. The construction of the 'Phase 1' of the same development scheme was completed on the opposite side of the road just before the start of the 'Phase 2' project.

This was a 'design - and – build' project, and therefore the main contractor had the main financial and design risks of the project. The project aimed to be awarded 'BREEAM[2] Excellent' certificate for its sustainability performance. The design was first developed to the level of detail needed for appointing the main sub-contractors with design responsibility (i.e. the construction proposals were prepared, and the design was developed to RIBA[3] Stage D – design development) under the coordination of the main contractor. This initial period of design development mainly involved the mechanical and electrical engineering (M&E) consultant, the structural engineering consultant, and the architect. The researcher started to observe the project after the M&E sub-contractor was appointed to took over the design and installation of the M&E works for the project. However, even after the M&E sub-contractor was appointed, the M&E consultant stayed on board as a consultant for the client. The main contractor, architect and M&E sub-contractor companies of the EduBuild project were the same as the Phase 1 project with largely similar team members in their teams. When the researcher started to observe this project, the structural engineering design and installations were largely completed. Therefore, the researcher observed a

[2] BREEAM stands for 'Building Research Establishment Environmental Assessment Method'. It is a method for assessing, rating, and certifying the sustainability of a building. It is developed by the Building Research Establishment (BRE).

[3] 'RIBA' stands for Royal Institute of British Architects. The RIBA stages used in the text refer to the RIBA Plan of Work which is the building design and construction process developed by the RIBA. The coding of the stages used in the text are from 'The RIBA Outline Plan of Work 2007' and reflect the wording used by the practitioners in their interactions.

relatively smaller number of meetings in which people responsible for structural engineering design and installations were present.

The EduBuild project, like its predecessor Phase 1 project, was ambitious in its use of BIM. A fully coordinated model was aimed at the outset of the project with the purpose of using the design model for construction as well as for operation and maintenance purposes. The client had a BIM-literate team that had gained experience during the Phase 1 project, and other team members also had working experience in BIM-enabled projects. The project had clear naming conventions and Employer Information Requirements that were mainly documented under a ‘BIM protocol’, which was occasionally revisited by the client for making further adjustments.

A commercial BIM platform that involved multiple discipline-specific packages was chosen to be used as the shared BIM platform in the project. Additional software that was compatible with the platform was further implemented, such as the construction site management plug-in from the same software company. In addition to the shared BIM platform, there was also a digital document management system in place for the facilitation of design document exchange including the information models.

The design saw a significant change after the RIBA D stage, during which most of the fundamental decisions regarding building systems and main areas of the design had already been made. The client asked to increase the indoor space in the building, and this had serious implications on the design. The researcher started to observe the project short after this design change, and observed different types of interdisciplinary coordination activities (i.e. design coordination meetings, design workshops, model coordination and clash detection meetings) over a period of ten months.

The OffiBuild project

This was a new office building project which was planned to be the first building of an office development scheme. The design of the OffiBuild project started with a conceptual design competition where applicants were asked to develop concepts that emphasised interaction among the tenants of the building. The client’s vision was to create a hub for digital start-up companies, which generally start their business journey with a small number of people. The client aimed to have a building which would enable ‘innovation through interaction’ among different tenants in a high-technology working environment. However, it took the client more than one year after the completion of the conceptual design competition to assign a main contractor, and to take the design work forward under a guaranteed maximum price 'design – and – build' scheme.

The researcher observed the project design coordination meetings (DCMs) over a period of ten months. The researcher started to observe the project while RIBA Stage D (i.e. design development) was being undertaken, and kept observing it towards the end of RIBA Stage E (i.e. technical design) – beginning of RIBA Stage F (i.e. production information). During the period of observation, the type of the contract and approximate budgets for work packages were agreed in principle between the client and the main contractor as well as between the main contractor and design consultants. However, the final contracts were not signed neither between the client and the main contractor nor between the design consultants and the main contractor during the period of observation. The reason for this, as expressed by the main contractor of the project, was that a certain level of design maturity was aimed to be achieved to be able to attach an adequately mature design to the contracts. For example, although the overall budget of the project was initially fixed by the client for a particular design intent, the design was still subject to change depending on whether the mezzanine floor in the building would be confirmed by the executive board of the client organisation. Similarly, it was towards the middle of the observation period that the main contractor could start market testing the design, and before the market test, the main contractor was reluctant to sign a contract with a fixed price. Although there were no final building and/or design contracts in place, some interim payments were made to the main contractor by the client, and to the design consultants by the main contractor "*to keep them motivated*" as stated by the bid manager of the main contractor.

The client hired a project management company and the project management company assigned a client project manager (client PM) to the project who acted as the representative of the client. While the chief executive officer (CEO) of the client attended several DCMs during the observation period (especially during the first two months of the observation period), the client PM regularly attended the DCMs. The client PM acted both as a supervisor on behalf of the client and as a communication agent between the client and the design team when issues that needed to be coordinated between the design team and the client raised.

The client owned an operational office building next to the site where the OffiBuild project and further development scheme were planned to be built. The client organisation's considerations about the integrated management of both existing and new buildings led to the decision of procuring some specialist equipment and systems for the OffiBuild project through the existing facility management team. This implied that the design and installation of these equipment and systems were left outside the responsibility of the OffiBuild project team. This became an important aspect to be negotiated and coordinated during the design as different parties needed to clarify the scope of the design, procurement and construction.

Although there were no contractual mandates or agreements regarding the use of Building Information Modelling, the architect of the project adopted a model-based design process as it believed that model-based working was good practice. The architect decided to adopt an interdisciplinary approach to model-based working upon the consent of the structural engineering design consultant. Consequently, although there was no detailed documentation, strategies or plans for model-based working, models were used by the architect and the structural engineering consultancy as one of the central means of developing and coordinating the design. Some other members of the design team, such as the main contractor and the M&E consultant, had access to the model but were not involved in shared model development activities during the observation period.

The LabBuild project

This was a high-technology (and high-precision) equipment manufacturing laboratory construction project. It was in a science park where other high-technology laboratories and companies were located. The client had multiple buildings in the science park.

This was a 'design – and – build' project, and therefore the main contractor had the main financial and design risks of the project. Consequently, the design consultants were contractually responsible to the main contractor. It was a fast-tracked project in the sense that the design and the construction substantially overlapped in time. More specifically, the main structural frame of the building was steel, and it was designed and being built relatively quickly before the detailed decisions regarding architectural, mechanical and engineering designs could have been made. At the conceptual design stage, the main characteristics and aspects of the design had been decided and the work had been sub-contracted by the main contractor after the conceptual design stage. Consequently, the design was being developed by the architect and several sub-contractors under the overall coordination of the main contractor, which was responsible to the client for all design and construction related operations. Actors of the project that were involved in design development included the steelworks sub-contractor, the mechanical and electrical engineering sub-contractor, the clean room (i.e. a special type of highly insulated room for the production and testing of high-precision equipment) sub-contractor, and the architect. The client employed a project management company to act as the client representative. Additionally, the full-time employees of the client who were responsible for the estates management as well as the future managers of the laboratory were also heavily involved in the observed interdisciplinary interactions.

A widely-used commercial BIM platform that involved multiple discipline-specific packages was chosen to be used as the shared BIM platform in the project. The architect, the steel structure sub-contractor, and the M&E engineering sub-contractor contributed in model development under the coordination of the main contractor. The project used BIM in design and it was part of the contractual documents. However, before the observation period, the researcher had been told by the bid manager of the main contractor that the client did not know about BIM, and therefore the client was not clear about what they expected from model-based working in the project. However, it has been observed that this caused confusions between the design team, the client and the client representatives at the subsequent stages of the design. The researcher observed six meetings in the LabBuild project over a period of three months. The last four meetings that were observed in this project were about re-establishing the model-based working in the project after it was discovered that there were misalignments between the design models and site works as well as between the client expectations from model-based design and designers' approach to model-development.

The architect of the project was changed by the main contractor during the observation period due to the unmet design deadlines set by the main contractor. Therefore, the first two meetings that the researcher observed were attended by the representative of the first architect assigned to the project, whereas the following four meetings were attended by the representative of the second architect assigned to the project.

CHAPTER 4. INTERDISCIPLINARY DESIGN DEVELOPMENT IN PRACTICE

4.1. Introduction

Chapters 4, 5, and 6 adopt three different empirical foci to look at how 'organising' is accomplished in the observed projects from three different perspectives (i.e. as detailed in Section 3.3.2 in Chapter 3). The different Research Questions of the present research govern the subdivision of findings and analyses into these three chapters. This chapter, Chapter 4, centres upon Research Question (RQ) 1 – 'How is interdisciplinary design work accomplished in practice in BIM-enabled projects? How do people make sense of developing the design together in interdisciplinary design projects?'. This RQ is the most general one, and also it reflects the initial frame of inquiry of the researcher in exploring the BIM-enabled interdisciplinary design work. Figure 5 below depicts how this chapter is positioned in, and contributes to the study. The findings and insights gained through addressing this research question enable addressing further research questions (i.e. RQ 2, 3 and 4 in Chapters 5 and 6) through which the understanding of 'organising' that is established in this chapter is further refined.

Following Nicolini (2012), this chapter adopts an empirical focus on 'the oriented and concerned nature' of interdisciplinary design development practices for the presentation and analysis of the findings (see also Section 3.3.2 in Chapter 3 for a discussion of the adopted empirical focus). Nicolini (2012) argues that the accomplishment of a practice by practitioners is driven by a sense of 'what to do', and 'what ought to be done'. Consequently, the aim of this chapter is to bring forward this 'lived directionality' (Nicolini 2012) which drives the interdisciplinary design development practices, and hence, enables 'making sense of' and 'organising' interdisciplinary design development. Key to studying the 'oriented and concerned nature' of practices is to explore the 'practical concerns and matters': the ways the object of work is experienced by practitioners (Nicolini 2012).

According to the practice-based approach adopted in this study, 'organising' is continuously accomplished through the ongoing everyday activities performed in practices. Nevertheless, practices are never isolated or stand alone, but always connected to each other through people and objects. Therefore, to bring forward the 'lived directionality', it is also essential to explore how and why practices are interconnected at a wider scale, such as at project-level organisation. This methodology of moving among different levels of organising has been referred to as 'zooming-in' and 'zooming-out' in Sections 3.3.1 and 3.3.2 (Chapter 3).

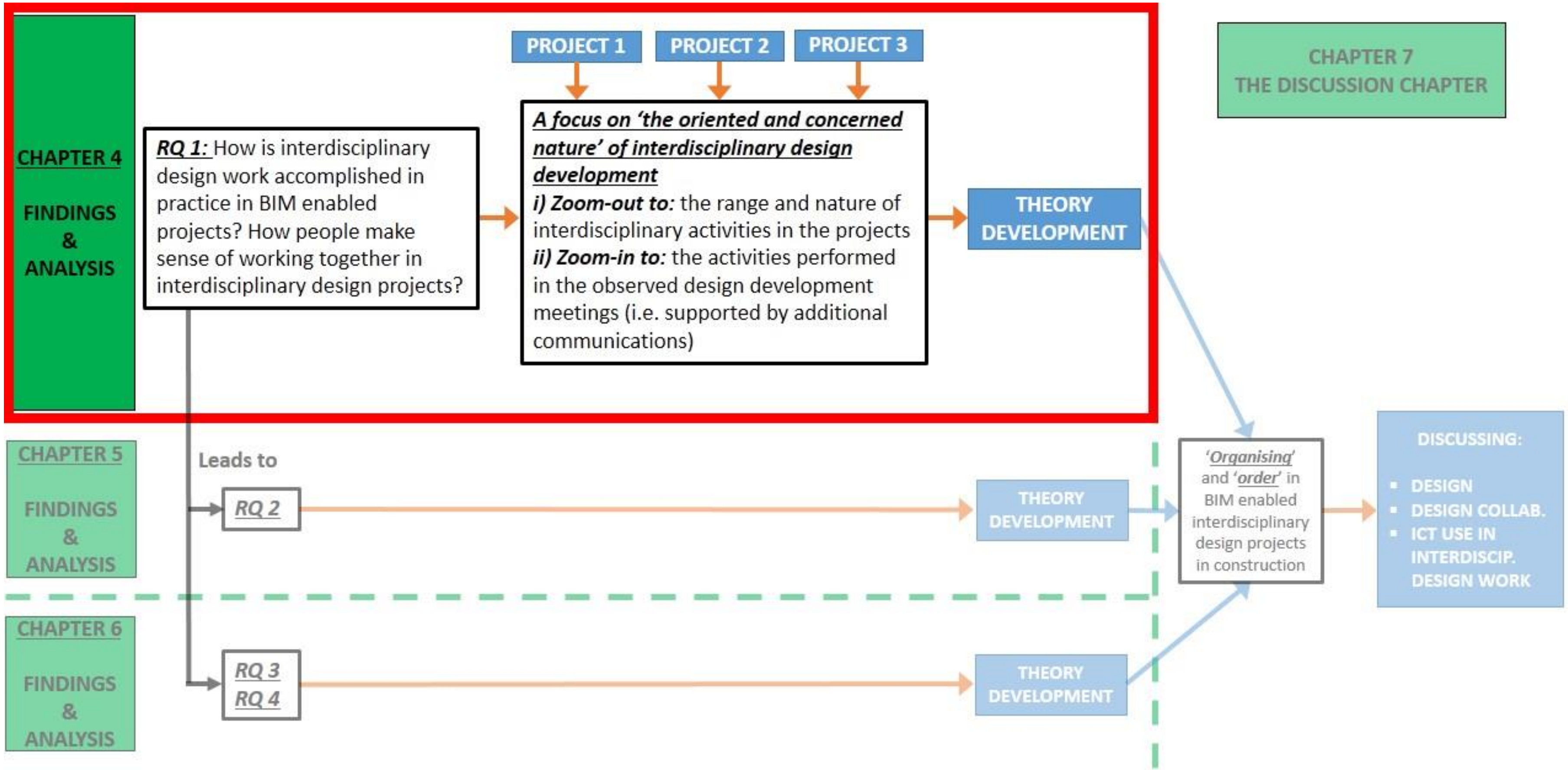

Figure 5 - The position of Chapter 4 in the study, and its contribution to theory development

Figure 6 below depicts the structure of this chapter in terms of its strategy for approaching to the empirical phenomena of interest, and developing theory from findings. As shown in Figure 6, the chapter starts with presenting first-order observations. This is done by presenting observations about 'the oriented and concerned nature' of interdisciplinary design development at two levels of organising; one being the higher-level of interconnected practices (in Section 4.2 - shown as 'zoom-out' in Figure 6), and the other being the lower level of individual practices (Section 4.3 - shown as 'zoom-in' in Figure 6). It is important to understand both levels as interrelated/mutually dependent (i.e. 'zooming-in' and 'zooming-out' between the two levels) because while 'zooming-out' provides an understanding of the 'context' within which practices take place, 'zooming-in' provides an understanding of how the 'context' is continuously (re-)produced through the activities (i.e. doings and sayings) that are performed in practices.

Therefore, this chapter first presents a higher-level (i.e. more-abstract) account of organising interdisciplinary design development (Section 4.2 - 'zoom-out' in Figure 6) through the presentation of the observations about the patterns in interdisciplinary interactions for design development in the observed projects, and their interconnections. This corresponds to presenting an overview of the 'changing nature and range of interdisciplinary interactions for design development'. After this, the chapter presents observations from the interdisciplinary design development meetings (Section 4.3 - 'zoom-in' in Figure 6). This corresponds to the presentation of the kinds of activities that were performed in these meetings to reveal what mattered to practitioners, and therefore to reveal the manifested 'orientation' of interdisciplinary design meetings. Having presented the first-order observations, Section 4.4 thematises these findings into three overarching 'practical concerns' of interdisciplinary design development. These themes of 'practical concerns' provide explanations about what was it that was achieved through the ongoing performance of the activities presented in the previous sections. Following this, a theoretical explanation about the 'lived directionality' of interdisciplinary design development practices is developed based upon the established themes of 'practical concerns' (see Figure 6). It is argued that this 'lived directionality' enabled practitioners to make sense of what to do, and what ought to be done in interdisciplinary design development, thus, made the practices 'intelligible' (i.e. meaningful), and 'organising' possible. In Section 4.5 a discussion is held to develop an explanatory organisational concept that addresses the RQ 1.

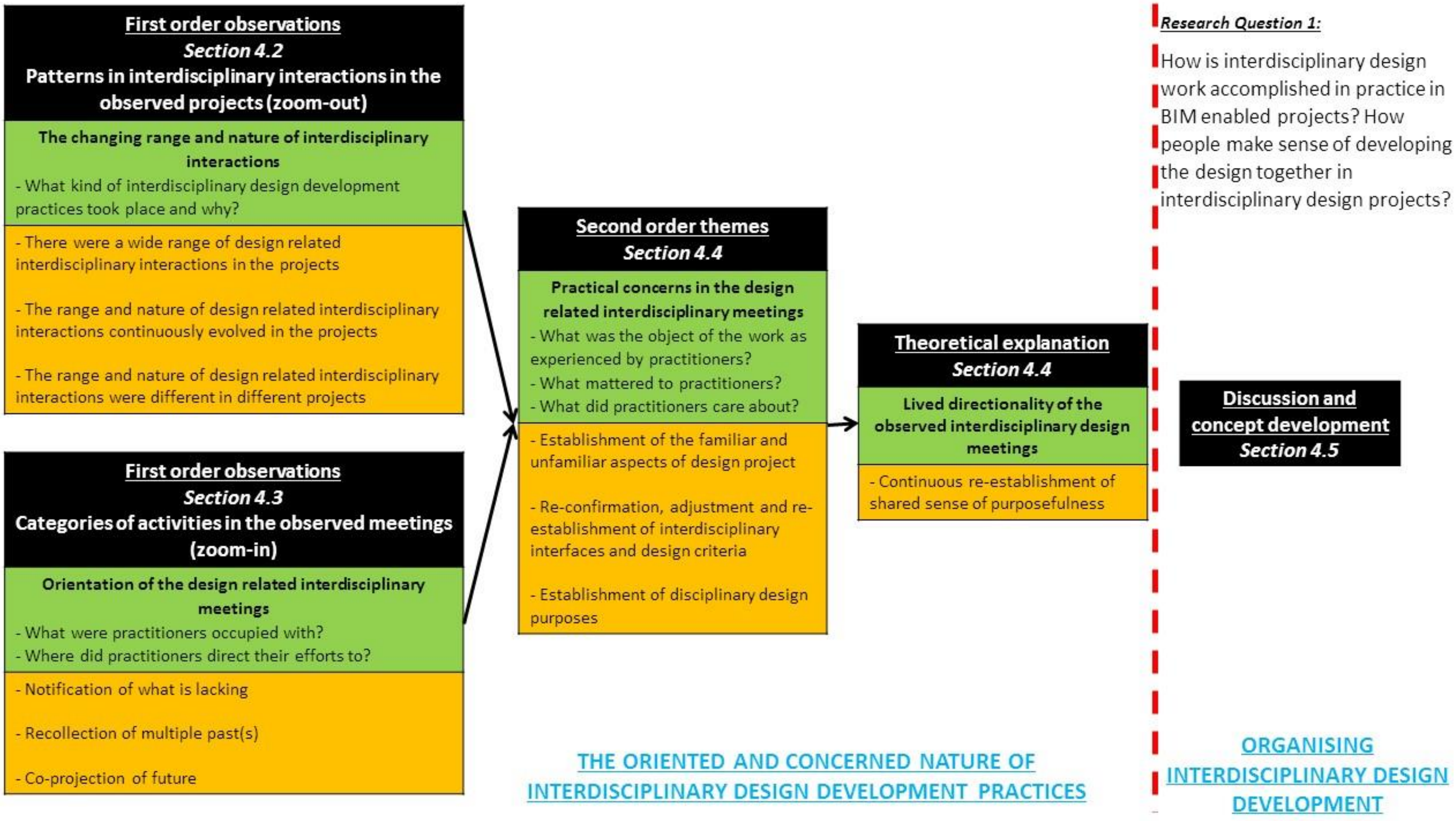

Figure 6 - Data, analysis, and theory development structure of Chapter 4

4.2. Changing Range and Nature of Interdisciplinary Interactions for Design Development (zoom-out)

4.2.1. A range of interdisciplinary interactions

A common aspect of the studied projects was the variety of interdisciplinary interactions for design development. These interactions can be grouped under two main categories: face-to-face interactions, and remote interactions. Face-to-face interactions included scheduled meetings, site visits, unscheduled meetings (i.e. spontaneous meetings) and informal conversations. Remote interactions included e-mail correspondences, telephone conversations, and those that involved the use of design artefacts such as checking, reviewing, marking-up, signing-off, and commenting on the design documents produced by other practitioners.

This variety did not necessarily imply a toolbox that included several well-defined kinds of interactions that were used to resolve distinct and well-defined design issues. On the contrary, interdisciplinary interactions were almost always in flux and resolution of interdisciplinary design issues actually included iterative series of notifications, explorations, expressions, and planning through a number of emergent interdisciplinary interactions. In this regard, interdisciplinary interactions for design development almost always pointed to subsequent interdisciplinary interactions and framed them. A sketch sent as an e-mail attachment, a phone conversation about design criteria of a building system, a contested space in building (which surfaced in a previous meeting) could trigger planning for further interactions to resolve the unfolding issues and develop the design gradually. For instance, in the EduBuild Project, there was a high number of meetings that focused on specific parts of the design, such as coordination of furniture with power outlets. It was observed that the decisions to hold these focused 'coordination workshops' were generally taken when an increasing number of issues started to surface about certain parts of the design; and therefore, coordination through other modes of interaction was not practical anymore. Although in-discipline work, (i.e. and therefore remote interdisciplinary interactions) and most of the face-to-face interactions for design development were not observed in this research, many references were made to the unobserved interdisciplinary interactions that revealed the connected and unfolding nature of design development.

Connected and unfolding nature of various kinds of interactions for design development implied that practitioners skilfully employed various modes of interactions (i.e. a range of face-to-face and remote modes of interactions). In practice, this meant being aware of, and exploiting, different strengths and weaknesses of each available mode of interaction in a complementary way. For example, in all the projects that were observed, most episodes of discussion in regular design-coordination meetings were concluded by agreeing on some action points involving further remote interactions, such as commenting on, reviewing, or marking-up some design documents related to the topic of discussion. In such cases, face-to-face discussion of an issue (e.g. ventilation of a ground floor) complemented remote interaction about more-detailed aspects of that issue (e.g. reviewing the schedule of outlets on the ground floor) and vice-versa (i.e. remote interactions that resulted in discovering new issues required these new issues to be discussed face-to-face).

Another example was the site visits. Although the observed projects were at different stages of design, and had different paces of physical construction on site, site visits and site photographs were used in all projects to reconsider the issues that were already identified and/or to discover new issues that only became perceptible by people physically being on site. For instance, although observation of the OffiBuild Project ended before the start of the construction of the superstructure on the site, and the site and its surroundings had been digitally scanned in three dimensions, even the OffiBuild design team organised some site visits to investigate the physical site first hand. In the meeting when the decision to organise a site visit was taken, the design manager of the main contractor claimed that "*it is important to get a feeling of it [the site]*". This was a statement supported by the other members of the design team through arguments such as "*we need to see the situation of the access roads*" and "*we need to check the existing retention wall*".

Complementary interdisciplinary interactions not only enabled various perspectives to be considered, but also provided the opportunity for a strategic use of them to optimise the interdisciplinary design development effort needed. For example, in the observed projects, in most of the cases of minor change requests (between different disciplines), the practitioners did not consider following a formal Request for Change procedure, due to its time-consuming nature. Instead, they only asked each other to "*drop a line*" (i.e. sending an e-mail) to have written evidence about the request in case of future conflicts, and/or for future references. In this respect, a range of interdisciplinary interactions for design development were used strategically, concurrently, and in a complementary way to address various kinds of unfolding design issues.

4.2.2. The evolving range and nature of interdisciplinary interactions

Two of the studied projects (i.e. the EduBuild Project and the OffiBuild Project) were observed over long periods (each for ten months), which allowed the researcher to develop insight into how the range and nature of interdisciplinary interactions for design development changed temporally in these projects. During the relatively shorter period of observation of the third project, the LabBuild Project, design development required a series of unexpected and unplanned interdisciplinary interactions to handle a situation of conflict. Overall, these observations revealed that the need for interdisciplinary interactions evolved during projects in both expected and unexpected ways. Practitioners responded to this by employing various modes of interactions in varying combinations based upon their perceptions of what needs to be done, and strengths and weaknesses of each mode of interaction. Therefore, it was revealed that the skilful use of various modes of interactions also included an appreciation of the changing needs of interacting to address the evolving needs of design development.

For example, the present researcher started to observe the OffiBuild Project while the RIBA Stage D (design development) was being undertaken, and continued to observe the project until the end of the RIBA Stage E (technical design) / the beginning of the RIBA Stage F (production information). During this period, the main mode of face-to-face interaction for design development was the weekly Design Coordination Meetings (DCM). There was very little additional face-to-face interaction that took place during the observation period. Nevertheless, the number and professional backgrounds of the participants, the types of the issues discussed, the objects that were used in these discussions changed remarkably over time. For instance, during the first two months of the observation period, discussions were held using the projection of a 3D model on a projection-screen in a meeting room. The model did not include much detail but was deemed to be sufficient for having system-level discussions about matters, such as the pros and cons of various potential types of cladding and roofing systems. However, towards the end of the observation period, most of the time was spent reviewing 2D drawings by projecting them on projection-screen in the meeting room, and having much more detailed discussions, such as discussions around the material and profile of the handrails on the edge of the mezzanine floor.

Also, the range of remote interdisciplinary interactions for design development changed during the observation period of the OffiBuild project. For example, with the advancing design, stakeholders started to increasingly discuss and set procedures for the publication, review and approval of produced drawings. This was due to the increasing number of documents that needed to be produced and detailed in a coordinated manner. This was indicative of an increasing number and variety of remote interdisciplinary interactions. Towards the end of the observation period, stakeholders decided to plan for a series of additional meetings (meetings like the ‘coordination workshops’ held in the EduBuild project which are mentioned in the previous section) concerning specific parts of the design where there were too many unresolved or revisited issues bouncing back and forth among various disciplines.

The EduBuild Project was also observed over a period of ten months in its detailed design stage. Although the observation period in the EduBuild project covered only this stage, the changing nature and range of interdisciplinary interactions for design development were also observed. For example, the number of site visits increased during the observation period. During the first two months of the period observed, the design team had been visiting the site together once a month to discuss design issues and to identify potential challenging areas of design. However, with the increasing detail in design packages and increasing number of site installations, the members of the design team started to visit the site more frequently to align the design development and the actual situation on the site closer. This also significantly increased the number of references made to site visits during the discussions in DCMs. Moreover, the focus of the references made to these visits also changed over the observation period revealing the changing nature of circumstances viewed during the group site visits. There was a gradual change in the topics of the references made to site visits from building areas and systems, to specific components in specific areas, and ultimately to the tests of the installed systems.

Although the LabBuild Project was observed for a considerably lesser amount of time compared to the two other projects, it also exhibited signs of the changing range and nature of interdisciplinary interactions for design development. Figure 7 shows a monthly schedule of design team meetings for the LabBuild project. As can be seen from the list, a range of design areas were discussed in the contractor design meetings, or client design meetings, according to the stage of development of the design. While the main contractor design meeting agenda was more about the detailed design issues, the client design meetings were more about the less-developed areas of the design where the client's inputs were instrumental. Once a part of the design reached a certain level of development, it then became an issue for main contractor design meetings for more-detailed coordination.

One common aspect of the changing range and nature of interdisciplinary interactions for design development was that most of the time practitioners knew that they would be dealing with changing types of issues over the design project. Therefore, the most suitable modes of interaction had to be continuously considered for the issues at hand.

Design Team Meeting Schedule

Tuesday will continue to be Main Contractor internal design meetings and Thursday will be Client meetings.
Main contractor meetings will be held in the Site Offices and Client meetings are likely to be in ... Building.

W/c	Tuesday	Thursday
11/8	Review section 1.2 of Buzzsaw and move pertinent drawings to Construction Issue 1.5.	
18/8	Mtg – Internal Walling Review - Blockwork o Setting out o BWIC o Lintol Schedules o Head Restraints o Wind posts Dry Lining Detailing o Setting out o BWIC o Abutment details o Acoustic detailing o Fire stopping Attendance Required – Architect & Structural Engineer	Mtg - Provisional Sums - Reception Area Enhancement - External Feature Lighting & Signage • Landscaping Review o Including Off-setting for BREEAM Attendance Required – Main contractor, Architect, & M&E sub-contractor, Client Team
25/8	Mtg – BREEAM Review of credits and evidencing information to be submitted. Attendance Required – Architect, M&E sub-contractor, Structural engineer	Mtg Provisional Sums - Reception Area Enhancement - External Feature Lighting & Signage - Internal Finishes Attendance Required – Architect, M&E sub-contractor. - Setting Out of Power & Data Outlets - Final positions of Group 3 Equipment - Location of Process Water Outlets Attendance Required – Main contractor, M&E sub-contractor and Clean rooms sub-contractor, Client team
1/9	Mtg – Metalwork Review - Staircases - Plant decks - Secondary steel - Cat ladders Attendance Required – Main contractor, Architect, Structural engineer, and Structural engineering sub-contractor (sub-contractor)	Mtg – Fire Alarm System & Strategy Review Attendance Required – Main contractor, M&E sub-contractor, Clean rooms sub-contractor, Client team
8/9	Mtg - Door Schedule Review - Metal Doors - Timber Doors - Roller Shutters - Lock Suiting - Supporting details Attendance Required – Main contractor and Architect - further input may be required from M&E sub-contractor and Clean rooms sub-contractor in due course.	Mtg • Commissioning Strategy Review • Servicing Strategy Attendance Required – Main contractor, ..., M&E sub-contractor, Clean rooms sub-contractor, Client team
15/9		
22/9		
29/9		

Figure 7 - A monthly design team meeting schedule of the LabBuild Project

The monthly meeting schedule provided in Figure 7 is an example of this situation. According to the example provided in Figure 7, the agenda items and participants were determined in advance and a suitable mode of interaction (i.e. in this case, face-to-face meetings) was arranged. However, although these meetings were expected, it did not mean that the expectations were aligned among different members of the design team. In other words, although the members of different disciplines were familiar with the 'journey' of the design project as a development path, often their expectations did not completely align or overlap during the observed meetings. For example, in one of the observed client design meetings in the LabBuild project, the design manager of the main contractor was expecting some initial drawings regarding external lighting, but the architect brought only some photos of the external lighting fixtures "*to give a feeling of*" what could be done with the budget in hand.

This resulted in a conflict due to different perspectives about what the design should be about at that particular point of development of the external lighting design.

These examples show how interdisciplinary interactions for design development evolved in the face of a mixture of mutually expected, differently expected, and unexpected, needs for interacting in each project. Thus, they also reveal the significance of the relationship among in-discipline work and interdisciplinary interactions for design development. The available modes of interaction were skilfully used to respond to changing needs, which resulted in different ranges and natures of interdisciplinary interactions for design development in each project. This implies that the observed projects had both similarities (i.e. due to the similarities of design projects) and differences (i.e. due to the peculiarities of specific design projects) in their changing range and nature of the interdisciplinary interactions for design development.

4.2.3. Different ranges and natures of interdisciplinary interactions

The observed projects had several similarities, nevertheless the ranges and natures of the interdisciplinary interactions for design development in these projects had also some significant differences. First, the observed projects were all 'design-and-build' projects, which dictated a certain structure of hierarchy in their organisation. In the 'design-and-build' contracting environment, the main contractor takes the main financial risk regarding both design and construction operations through a direct contracted relationship with the client. Therefore, the main contractor's design team acts as the main coordinator of the entire design project, which was true for all the projects that were observed. Second, all projects were new-build projects that took place in the UK. Third, there were common types of consultant and contractor in the different projects. The most significant similarity in these terms was between the EduBuild and LabBuild projects. The main contractor was the same in these projects.

Despite these similarities, all projects had different ranges and natures of design-related interdisciplinary interactions for design development. It was observed that several factors contributed to these differences. First, the building types were different in terms of their intended functions. One was an office building, another one was an educational building, and another one was a laboratory building. This resulted in some differences in design development. For example, in the LabBuild project, the specialist contractor that was responsible for the design and construction of the 'clean rooms'[4] was given priority in any decision that was related to those rooms. Similarly, in the OffiBuild Project, opinions of the IT Manager of the client were prioritised over the electrical engineering consultant's propositions regarding the designs of power and data outlets. This was justified by the client's vision of creating an innovation hub for digital start-ups, where 'open innovation' could be engendered. This particular aspect of the building in the OffiBuild project affected the patterns of interdisciplinary interactions by giving a significant role to the IT Manager of the client organisation, who represented this vision in the design team. Overall, the particular aspects regarding the functions of the buildings resulted in differences in the range and nature of interdisciplinary interactions for design development.

Second, the observed projects had different phasing strategies for the design which influenced the overall patterns of interdisciplinary interactions for design development in general. For example, the LabBuild project was a fast-tracked project where the construction of the structural frame of the building was given initial priority. The decision was taken due to the fast assembly on site afforded by steel frame structures. This led to an intense and relatively independent structural design at the beginning of the project, followed by the early start of the construction on the site when other disciplines of design were still at relatively early stages of design. The situation for the OffiBuild and EduBuild projects were significantly different to the LabBuild because in these two projects the design of various building systems progressed at a mutually adjusted pace. The different phasing approach to the design of the LabBuild project resulted in a different general pattern of interdisciplinary interactions for design development. For instance, the site visits in the design development played a more fundamental role in the development of the design in the LabBuild project. Although the other two projects were observed for much longer periods of time, more site visits in the LabBuild project were attended in comparison to the other two projects. This was particularly significant considering that the observed stage of the LabBuild project was overlapping with the observed stages of the other two projects (i.e. the end of the observation period of the OffiBuild project, and the beginning of the observation period of the EduBuild project had many overlapping aspects with the observed stage of the LabBuild project in terms of levels of development of designs).

[4] 'Clean rooms' were the rooms in which high-sensitivity equipment would be manufactured. Therefore, a special set of specifications and a specialist sub-contractor were in place for the design and construction of these rooms to ensure very low-level of environmental pollutants, such as dust.

Third, the historical aspects of the projects were different, and these differences were noticeable in the organisation of interdisciplinary interactions for design development. For example, most of the members of the design team of the EduBuild project had recently worked in the design of another educational building for the same client right before the start of the EduBuild project. The decisions regarding what kind of modes of interactions needed to be used for the issues in hand heavily relied on this past joint experience. At the beginning of the furniture and power outlets coordination workshop mentioned previously, the representative of the Mechanical & Electrical Engineering (M&E) sub-contractor openly stated this situation, and said that "*in the Phase 1 project lots of unanticipated problems occurred when the furniture started to be placed in the building. The aim of this meeting is to coordinate the furniture and electrical outlets to prevent such problems*".

Historical aspects could also be apparent in different ways such as previously established procedures, documents, or standards. For example, in the LabBuild project, the client organisation owned several buildings for which there was an established room and hazard coding system. This required the architect to liaise with the facilities management department of the client organisation for the development of the design of signage. On the other hand, in the OffiBuild project, assignment of numbers to rooms was seen as an issue which could be developed by the architect, and reviewed by the project manager who represents the client, and did not require further liaison with any additional actors. The historically established document management systems and procedures of various design stakeholders were also influential in determining the range and nature of interdisciplinary interactions. For instance, in the OffiBuild project, the main contractor assigned two document management officers who were responsible of the overall coordination and quality inspection of published documents according to the document management procedures of the main contractor. Therefore, those two people became important points of contacts for the other members of the design team in interdisciplinary interactions for development of the design.

Finally, contractual obligations also played an important part in determining the range and nature of interdisciplinary interactions for design development. For example, in the OffiBuild and EduBuild projects the level of sustainability certification, which was part of the contractual requirements, determined what specialist consultants needed to be hired and how they should be involved in interdisciplinary interactions for design development.

These kinds of differences, when considered with the differently expected and unexpected needs of design development, implied different ranges and nature of interdisciplinary interactions for design development in the observed projects. The practitioners employed available modes of interactions based on their perceptions of the evolving needs of design development, and the suitability, strength and weaknesses of each mode of interaction.

4.3. Orientations of the Interdisciplinary Design Meetings (zoom-in)

It has been already stated in Section 4.2 that in the observed projects, interdisciplinary design meetings (i.e. meetings in which issues about development of design were discussed) were part of a larger number of unfolding interdisciplinary interactions for design development; and numerous references were made to other interdisciplinary interactions during the observed meetings. In this section, this unfolding nature is explored.

This is done through presenting the 'orientations' of the observed interdisciplinary design meetings with the ultimate purpose of foregrounding their 'lived directionality' (Nicolini 2012). In establishing the 'orientations' of the interdisciplinary design meetings, the flows of the observed meetings in general, and the kinds of issues that occupied the practitioners in particular, are highlighted. Considering the connected and unfolding nature of various kinds of interdisciplinary interactions for design development (see Sections 4.2.1 and 4.2.2 in this chapter), the 'lived directionality' of the observed interdisciplinary design meetings is assumed to be the 'lived directionality' of the interdisciplinary interactions for design development in general.

4.3.1. The three main kinds of activities

As explained in Section 3.3 (Chapter 3), in practice-based research, a 'frame' consisting of i) an empirical focus to foreground certain aspects of practices; and ii) a developing vocabulary to capture the relations in and among various levels of organising, is required to understand, discuss, and analyse practices. The empirical focus of this chapter has been set as 'the oriented and concerned nature' of interdisciplinary design development. Considering the large amount of data collected from the interdisciplinary design meetings, an overarching vocabulary needs to be set to meaningfully describe the activities performed in the observed practices. This section sets three main kinds of activities for this purpose: '*notification of what is lacking (clarity)*', '*collective re-collection of multiple past(s)*', and '*co-projection of future*'. These are argued to be the main kinds of activities that the practitioners were occupied with during the observed interdisciplinary design meetings, and therefore reflect the manifested 'orientation' of interdisciplinary design development meetings. This allows the meaningful presentation of the findings in accordance with the empirical focus set for the chapter. The three main kinds of activities are explained below in more-detail before used in presenting findings from the observed interdisciplinary design meetings in the following sections.

In the studied projects, the kinds of issues discussed in the observed interdisciplinary design meetings showed differences. As argued previously, peculiarities of the observed projects (i.e. different building types, different organisational actors and structures, different design phasing approaches, and so on) resulted in different ranges and natures of interdisciplinary design meetings. However, these meetings also had similarities in terms of being 'oriented'. More specifically, the meetings:

i) had more-or-less clearly defined agendas that structured the scope of the meeting;

ii) had participants that were thought to be relevant to the anticipated scope of the meeting;

iii) involved objects that were thought to be relevant to the anticipated scope of the meeting.

The agendas of meetings provided a general orientation regarding what to look for, or what to pay attention to, and what to neglect or plan for further remote or face-to-face interactions. This general orientation was also important because it determined from what angles and to what extent the raised design issues would be discussed in the meeting. In this respect, the agendas of meetings provided the foundation of what to talk about and how, thus, drawing a frame for discussions that determined the nature of the issues discussed.

In the observed projects, interdisciplinary design issues appeared in terms of '*lacks of clarity*' regarding a part of design product (i.e. the building) and/or design process that needed to be resolved to enable progression of design. Varying agendas of distinct interdisciplinary meetings provided a variety of platforms and perspectives to resolve and further '*notice what had been lacking (clarity)'*. During the observed meetings, once '*what had been lacking*' was raised or noticed in terms of a 'design issue', interdisciplinary efforts were directed at '*recollection of multiple pasts'* that are related to the noticed 'design issue'. More specifically, the parties who had a stake in the discussed issue contributed to the discussion to reflect their own understanding of *what was lacking*, based on both their individual professional past experiences and the '*shared past*' (i.e. their history of working on a project together) that were perceived to be relevant to the issue at hand. These discussions were directed to '*co-project'* what needed to be done next, to handle the issue in the light of the collectively recollected past. Nevertheless, '*notification of what is lacking (clarity)', 'collective recollection of multiple pasts*', and, '*co-projection of future'* were not always performed in a linear or smooth way.

Discrepancies in *noticing*, *recollecting* and *projecting* among members of the design team required time and effort to be adjusted, thus making discussions effortful. Moreover, these three types of activities were entangled, and they related to each other in complex ways in many instances, thus, these three activities were mostly far from being linear and neatly organised in discussions. This meant that, in many instances, discussions about design issues involved a complex series of *notifications*, *collective recollection of the multiple pasts*, and *co-projection of the future* until the parties of the discussion agreed on a *co-projected* course of action about the discussed issue. The criteria of this agreement depended upon the main orientation of the meeting, or in other words the perceived agenda of the meeting. It is in this sense that the agenda (i.e. documented and perceived) provided a general orientation. Aggregation of numerous interdisciplinary interactions in the projects shaped both documented and perceived agendas of the subsequent meetings (and interactions), thus creating a progressive series of interdisciplinary design meetings and interactions. This meant progressive '*notification of what is lacking', 'collective recollection'* and *'co-projection'* enabled progressive development of the design.

Examples from the studied projects are presented below to expose how seemingly different interdisciplinary design meetings in different projects centre upon patterns of activities relating to '*notification of what is lacking*', '*collective recollection of multiple past(s)*' and '*co-projection of future activities*'. This provides an explanation of what practitioners were occupied with during the observed interdisciplinary design meetings, and where they directed their efforts, thus showing a detailed account of the orientation of the observed interdisciplinary design development meetings.

4.3.2. Orientation of the interdisciplinary design meetings in the EduBuild project

In the EduBuild project, two kinds of interdisciplinary meetings for design development were dominant during the detailed design stage that was observed. One of them was the fortnightly 'Design Coordination Meetings' (DCM) which had regular attendants and a fixed agenda structure. The DCMs in the EduBuild project were the arena where anything regarding the developing design could be discussed, and therefore all the active members of the design team participated the DCMs. The other kind was the 'coordination workshops' which were planned and held according to emerging, more-specific coordination needs of the developing design. The timing of the coordination workshops depended on the perceived benefit of sparing face-to-face time for handling a specific part of the design (e.g. coordination of audio-visual equipment and electrical services), and therefore was highly variable. The participants of the coordination workshops depended on the particularities of the issues that would be addressed. For instance, for the coordination of the audio-visual equipment and electrical services, representatives of the client, main contractor, electrical engineering sub-contractor, specialist audio-visual equipment sub-contractor and architect were present. The flow and agenda of the coordination workshops were determined according to the particulars of the issues that were to be tackled. Below the DCMs are presented, followed by the coordination workshops.

4.3.2.1. Design Coordination Meetings

In the EduBuild project, agendas of regular fortnightly Design Coordination Meetings (DCMs) consisted of two main parts (see Appendix 2 for an example). The section that addressed the minutes of the previous meeting included bullet points to be discussed regarding specific design issues about specific systems of the building. These points were included in the agenda until they were resolved. The 'updates' section of the agenda included presentation of an overview of the recently completed and upcoming work by each design discipline, including statements about recently produced information and information needed from the other members of the design team. The 'previous minutes' section required attendees to cover the listed issues one-by-one, and discuss the issues between relevant parties to come to an agreement regarding how to proceed. Once a point entered in the 'previous minutes' section of the agenda, it would remain in the agenda until it was resolved but the discussions on the point would generally take much longer when it appeared in the agenda for the first time. If there was no deviation from the initially planned course of action, the second and further discussions about the same agenda item were generally about re-confirmation and monitoring of the planned course of action for the resolution of the issue.

The bullet points in the 'previous minutes' section provided leverage both for *notification of what was lacking* and *recollection of the past*. For example, the statement below is taken from the 'previous minutes' section of one of the DCMs in the EduBuild project:

> "*Ceiling tile option to be adopted for return air in lieu of linear diffusers. Mock up to be erected in Phase 2 with light fittings for review.*" (21.05.2014 – EduBuild Project – DCM)

This statement tells what the issue is about (i.e. choosing return-air inlet type), what is *lacking* to proceed with the design (i.e. a mock up is needed for further confirmation of the proposed air inlet type), and also includes clues about the past (i.e. the proposed air inlet type is different than what was previously used in the Phase 1 project). Although previously discussed agenda items such as the one provided above were generally passed faster than new issues, this was not always the case. For example, although the point above was discussed in the previous DCM when it was first added to the agenda, in the following DCM it triggered a discussion regarding the review of the proposed light fittings by the client and coordination of the light fittings schedule between the architect, mechanical and electrical engineering (M&E) consultant and M&E sub-contractor. Consequently, keeping the unresolved issues in the agenda not only enabled the practitioners to re-confirm and monitor the agreed course of action around the issues but also triggered further *notifications of what was lacking clarity*.

In the 'updates' section, each representative of each discipline had an opportunity to provide updates for the design team. This included two main types of discussion. First, members of the design team raised some new specific issues that would be added to the 'previous minutes' section of the agenda of the following DCM. Second, one representative from each discipline provided a general discipline-specific update regarding what they had been working on recently, what they were planning to deliver next, and the information they published and expected in relation with these. Occasionally, explanations from different disciplines about the recently completed and upcoming work triggered *notifications of what was lacking clarity* regarding the completed and upcoming design development activities, and led to discussions.

This agenda structure of the DCMs fulfilled two important roles for the *notification of what was lacking clarity*. First, it provided an arena to expose the *lacks of clarity* noticed elsewhere to multiple disciplines and thus, enabled further *notification* of potentially related design issues. Second, it provided an arena to keep the active members of the design team up-to-date regarding actual design development activities so that all members of the team could get a chance to *notice what was lacking clarity* in terms of the actualities of the ongoing design project.

The most significant factor in adjusting the efforts in the DCMs of the EduBuild project was the 'expectedness' of the design issue. Indeed, this was also the main criterion that separated 'previous minutes' and 'updates' sections of the agenda. As stated above, both sections could trigger *notification* of both 'expected' and 'unexpected' issues. Nevertheless, 'previous minutes' section was mainly consisted of unexpected *lacks of clarity* that needed to be first grasped through interdisciplinary discussions, and then addressed and tracked with interdisciplinary care since they were 'unexpected'. On the other hand, 'updates' section was mainly for the *lacks of clarity* that were expected as a result of the individual past professional experiences as well as the *shared past* of the design team in engaging with each other around the design issues.

The EduBuild project was observed during its detailed design stage when most of the strategic design decisions which provided direction for further design activities were already made. Therefore, the design development in the EduBuild project was mostly about taking detailed design decisions and producing increasingly detailed design documents. Consequently, the efforts in DCMs of the EduBuild project were mostly for the *notification* and exploration of the *unexpected lacks of clarity* which presented issues that could not be addressed with the design strategies established, and the design discussions held in the past. The design team had a *shared past* (i.e. a history of working on a project together) that provided clues about how to proceed with design work at hand. It was only the things that could not be grasped or addressed through this past, required significant efforts during the DCMs. This aspect of the DCMs in the EduBuild project made it very difficult for the researcher to follow the discussions (especially at the beginning of the observation period). For example, the participants of DCM used hardly any drawings to talk about most of the issues and a very few indications were enough for them to understand which part of the building that the discussion was about. The statements such as "*do you remember our previous discussion about the acoustic baffles in the loading bay?*" facilitated the discussions among those who had access to the *shared past* while making it difficult for the researcher to follow who did not have access to it. The relevance and effect of the past showed itself also through the many references made to the Phase 1 project. Moreover, many times, practitioners used statements such as "*I should check*" and "*I should confirm*" to close discussions which meant that they needed to review the past documentation to be able to appropriately *establish what was lacking clarity,* and propose an appropriate course of action for its resolution.

There were also numerous expected *lacks of clarity* which were already known or previously noticed by the members of the design team. These expected *lacks of clarity* were treated significantly different than the unexpected ones. In this respect, the past (i.e. both the *professional and shared pasts* of the members of the design team) played an important role in determining what were expected and what were not. Both the 'previous minutes' and 'updates' sections of the DCMs were used as opportunities for *noticing what was lacking* *clarity* and whether they were expected or unexpected. Expected *lacks of clarity* were passed very quickly, sometimes with a single nod or gesture, whereas *unexpected lacks of clarity* were the ones that required much more time and effort in the DCMs.

For example, while covering 'updates' section of the agenda, any work that was announced to be completed by the architect or the M&E sub-contractor implied that further related work could be performed by the other. However, generally these were quickly covered without extensive discussion. Occasionally coordination workshops were quickly scheduled around expected *lacks of clarity* to focus on more-detailed aspects of them but in the DCMs, lengthy discussions about expected *lacks of clarity* did not take place. This was the main reason the 'previous minutes' section of the DCMs generally took much longer than the 'updates' section, which included news that was mostly expected by all members of the design team.

In cases where there were unexpected *lacks of clarity*, discussions included a complex series of *notifications of what was lacking clarity*, *collective recollection of the relevant past,* and *co-projection* of the future. These discussions continued until i) the parties involved in the discussion were convinced that the *lack of clarity* was identified to the necessary extent through *collective recollection of the past*; and ii) the future was *co-projected* to the required level of detail. Events EE 1 and EE 2 outlined below show instances of discussions in the face of unexpected *lacks of clarity*. These events expose the relation between *noticing what was lacking clarity* and establishing what was expected and unexpected in it. Therefore, these events show that both *the professional and shared pasts* played important roles in determining what needed to be discussed and the directions of the effort spent in the DCMs.

Project EduBuild - Event 1 (EE1) - Wooden Ceilings in the Board Room

> *In the EduBuild project, apart from the atrium area on the ground floor most of the areas were serviced through suspended/false ceilings. This was a very conventional system for such buildings, on which the representatives of the architect, the M&E consultant, and the M&E sub-contractor were experienced. Additionally, there were some agreed general design strategies between the M&E and architecture disciplines for working with these types of ceilings in the project. However, for the board room, the client briefing stated that "the ceiling in board room will be different" and the architect specified a decorative wooden ceiling. This had serious implications on several other systems, and a single irregular ceiling type decision required many following coordination. Firstly, the chilled beams that were specified for the board*

room appeared as an issue. The fixing details of both wooden ceiling and chilled beams, efficiency of chilled beams when placed above the wooden ceiling, the laying direction of the individual wooden pieces and chilled beams, the colour of wooden ceiling and chilled beams (because the chilled beams would be visible from the gaps between separate wooden pieces) were all needed to be discussed at different occasions in DCMs between the representatives of the architect who were responsible for the ceiling, the representatives of the M&E consultant who specified chilled beams for that space, and the representatives of the M&E sub-contractor who were supposed to deliver detailed design and install the services on the construction site. When this issue was first raised by a representative of the M&E sub-contractor, his first strategy was to understand the premises of this decision: whether the wooden ceiling was particularly specified by the client or the client only specified a different type of ceiling upon which the architect decided to have wooden ceilings. Once it was concluded that the further discussions with the client led the architect to specify wooden ceiling, all the issues mentioned above needed to be coordinated due to the irregular character of wooden ceilings in the project. The wooden ceilings needed to be coordinated for audio-visual equipment as well. For example, whether the speakers would be under or above the wooden ceilings was a coordination issue between the representatives of the architect and the M&E sub-contractor as this was related to the efficiency of the sound system as well as to the aesthetic aspects of the space (i.e. colour harmony between the speakers and the wooden ceiling).

Since the M&E sub-contractor joined the project after the completion of the early stages of the design, in Event EE 1 (EduBuild Project – Event 1), the representative of the M&E sub-contractor did not have access to the *shared past* regarding the special wooden ceiling type that needed to be installed in the boardroom. Moreover, the decorative wooden ceiling was an unconventional system for this type of building. Therefore, the past individual professional experience of the representative of the M&E sub-contractor did not enable him to resolve the issue himself, thus, required him to discuss the issue with the other members of the design team.

Project EduBuild - Event 2 (EE 2) – Servicing the Rooms in the Corners

The EduBuild project had seen a significant design change to increase the total net internal area of the building. Although the previous service and architectural strategies were reviewed before the confirmation of the design change, some areas *of the design needed to be particularly coordinated as they fell out of the general strategies. One example of this was about the servicing problems of the rooms in the corners on the floors above the ground level. The main servicing strategy for these floors was to pass the main services along the corridors on each floor, and distribute them in the rooms that open to the corridor. However, the rooms that stayed in the corners of each floor required additional coordination because they were in remote positions (i.e. largely isolated from the corridors) and their servicing needed to be specifically coordinated due to the number of the services that should pass through a very limited space. This issue stayed as an outstanding issue for long time as detailed drawings by the architect and the M&E sub-contractor were needed before the coordination could be done at the desired level of detail. The strategy followed in this situation was to coordinate one of the corner rooms in a very detailed way, and then to apply the agreed design principles to the other similar rooms. It had been thought that ongoing detailed coordination of all isolated rooms would take too much time.*

Event EE 2 implies the presence of an existing design strategy for the services of the rooms that face the corridors. Therefore, once a general design strategy was established for the service design of these parts of the building, *lacks of clarity* regarding them became expected and did not require further interdisciplinary discussion in DCMs until it was *noticed* that the strategy did not work for the rooms in the corners. Once this was *noticed*, *the lack of clarity* required a discussion in the DCM to *recollect multiple pasts* (i.e. professional pasts as well as previous decisions, discussions, documents, courses of actions regarding the design of services for those rooms), and *co-project* a course of action (i.e. wait until the architectural and M&E detailed designs are ready for the surrounding areas, and then hold a coordination meeting for one of the rooms and apply the discussed solution to the other corner rooms).

Co-projection of future was always about articulating a course of action around the *noticed lacks of clarity*. DCMs in the EduBuild project were open to every kind of design related discussion but it was mainly the unexpected ones that were bracketed and the subject of significant interdisciplinary attention and effort. Expected *lacks of clarity* could be handled through the already established coordination procedures or mechanisms and therefore did not attract much attention from the members of the design team. However, the ones that were unexpected required a complex series of *notification*, *collective recollection of the relevant past* and *co-projection* of potential courses of action for their resolution. For the unexpected *lacks of clarity*, *notification*, *recollection of relevant past,* and *co-projection* of future revolved around the questions like the following ones:

- What was the nature of the issue?
- What made a particular point to appear as an issue at that stage of the design?
- What was it related to: buildability, functionality, cost, time, quality?
- Was it stemming from a lack of information that was supposed to be produced or a lack of previously established meaningful design that was needed as a basis for further design development?
- To what extent was the issue known or expected?
- What were the potential implications of different possible design solutions/processes in terms of buildability, functionality, cost, time, quality and relations with the client?
- What kind of information or confirmation was required from which parties to proceed with or justify a design solution/action strategy?

In this respect, *co-projections* of what needed to be done around the unexpected *lacks of clarity* were within the confines of the already-established design and design processes. More specifically, resolution of the unexpected lacks of clarity had to be compatible with the existing design and design processes, and therefore the effort was spent to establish the unexpected *lacks of clarity* in terms of the already-established design and design processes. This orientation required revelation of previously established design strategies, assumptions and processes in a collective way. Discussion of implications of the unexpected *lacks of clarity* on the detailed aspects of the discipline-specific designs were not dominant. Rather, the practitioners who judged these implications revealed the important factors that needed to be considered in establishing and resolving the unexpected *lacks of clarity*. It is in this sense that the *multiple pasts* needed to be *recollected in a collective way*. As a result, *co-projection* of what needed to be done involved *co-projection* of concurrent actions for a number of stakeholders for appropriate establishment, and eventually resolution of the unexpected *lacks of clarity*. Event below (EE 3), shows how an unexpected *notification of a lack of clarity* was *co-projected* to be resolved. The event reveals that the noticed issue was grasped in consideration with several complex relationships with various actors and systems of the building. This required a complex series of *notification*, *recollection* and *co-projection* to come to an acceptable resolution of the unexpected *lack of clarity*.

Project EduBuild - Event 3 (EE 3) – Grills on the doors

> *In one of the DCMs, the representative of the M&E sub-contractor stated that the revised ventilation calculations, which were based on the revised design and occupancy rates, revealed that on one of the floors few doors needed to have transfer grilles to satisfy the ventilation requirements. The representative of the architect rejected this as soon as it was proposed. Following the rejection, the representative of the M&E sub-contractor provided the results of the ventilation calculations together with the story of the changing occupancy rates due to the revised design. After this explanation, the representative of the architect still insisted that having grilles on the doors in that area was not an option. The representative of the M&E sub-contractor accepted his objection, and stated that they would think about something else. After a short silence, the representative of the architect stated that the wall between those doors would be painted to the same colour as the doors, and therefore they would not want to have grey spots on the doors. The representative of the architect concluded that he would have a look at the issue, and think about it until the following DCM. In the following meeting, the representative of the architect stated that the actual number of the doors that needed to be equipped with grilles was much more than he anticipated. He stated again that the grilles were not visually good and asked other members of the team whether it was possible to omit them. One of the alternative ideas appeared as undercutting the doors. During the discussion of this option the representative of the architect stated that they needed to communicate the size of undercutting to the manufacturer, and also to make sure that the doors had not been produced and packaged yet. The representative of the M&E consultant added that the original intent was not having that many transfer door grilles on the doors at that area as part of the ventilation strategy. In parallel with the discussion of undercutting the doors, the representative of the architect asked the colour range of grilles, and even the option of painting the grilles on the site was discussed as a potential solution. However, the latter proposition then was found non-viable thinking about the long-term maintenance requirements.*

As can be seen from Event EE3, it can be argued that unexpected *lacks of clarity* triggered a complex series of *collective notification*, *recollection* and *co-projection* whereas expected issues followed generally a relatively linear and less effortful path of *notification*, *recollection* and *co-projection*.

Handling unexpected issues within the confines of the established design and design process implied approaching the *noticed unexpected lacks of clarity* with a situational pragmatism established through interdisciplinary discussions in DCMs. The attention, time and alternatives that could be assigned to design issues were limited. Therefore, whether to add the raised issues to the following DCM's agenda, and the appropriate level of detail to address the issue, depended on the particularities of the design issue and the necessities of the design stage. For example, when the time of the site installation of the risers approached, a participant *noticed* that the dimensions of the risers had to be updated based upon the changed design, before the installation started on the site. Nevertheless, after holding a discussion through which *the pasts were recollected*, it was revealed that the design team was very unlikely to collect all the necessary information to update the riser dimensions within the available time. Instead of *co-projecting* an action strategy for the early delivery of the necessary information, representatives of the M&E sub-contractor and M&E consultant agreed on that this was not an issue to be spent too much effort on, and the site installation could be done based upon the previously established dimensions. This was justified by the argument that the current dimensions of the risers would probably be enough for the new design situation, and even if they were not, changing the sizes of the pumps that would be connected to the risers would solve the problem, thus, there was no need to spend further effort on this as a design issue.

A similar situation happened around the coordination of ventilation and acoustics aspects of the video hub which was designed to be installed in the atrium area. *The lack of clarity*, *recollection of past,* and *co-projected* course of action regarding the design of this video hub is presented below as an event (EE 4).

Project EduBuild - Event 4 (EE 4) – Video Pod vs. Diary Pod

> *In one of the DCMs towards the end of the observation period, one of the representatives of the M&E sub-contractor raised the point that there were no services designed to feed the video pod in the atrium area. He argued that it was neglected in the initial design that was handed to them, and that it was not mentioned in the service strategy of the building which was part of the construction*

proposals. He started to ask about the design intent of this pod and its mechanical and electrical service requirements. The discussion revealed that the pod was originally designed by the architect to create an interactive experience for the students. It was planned to be a small, self-contained structure with a large screen and a bench in it. Upon this initial information, the representative of the M&E sub-contractor inferred that it needed to be ventilated and equipped with a power outlet. Nevertheless, the M&E consultant stated that the name 'video pod' sounded like it required a special acoustics performance that needed to be satisfied but she could not remember and therefore asked for this issue to be included as an agenda item for the following DCM. In the following DCM, the representative of the M&E consultant stated that she could not find any information regarding the acoustics needs of the pod, and she therefore needed to contact the acoustics specialist to ask whether any particular acoustics requirements were assigned for this pod. However, it was known from previous experience that the acoustics specialist had completed her job in the project long ago and was unwilling to devote further effort to this project. On the other hand, acoustics requirements of the pod became an issue mainly because of its ventilation requirement. The only way to ventilate the space was to install an independent fan in the pod and this would cause noise. Furthermore, the opening required to fit the fan would cause the noise in the atrium to enter the pod. After a discussion around acoustics implication of potential ventilation solutions, it was decided to contact the client to understand what exactly the pod would be used for to understand whether there were special acoustics requirements for the pod. In the following DCM, the representative of the M&E consultant stated that she contacted the representatives of the client and learned that the space was planned to have an interactive space between the educational institution and students but no specific activities for the pod were known at that moment. She further stated that she proposed to change the name of the space from 'video pod' to 'diary pod', and this was accepted by the client. She stated that changing the name of the space to 'diary pod' surely eliminated the possible high acoustics requirements of the space and therefore it was fine to proceed with an individual fan for the ventilation of the space.

Having established a general descriptive account of the three main kinds of activities that were observed in interdisciplinary discussions, it is also valuable to establish how individuals participated in, and behaved during the discussions to manage all the issues in hand in a reasonable amount of time (generally one and a half to two hours at the beginning of the observation period, and shorter as the project progressed). This will reveal how practitioners strategically directed their individual efforts to handle interdisciplinary design issues through a limited number of face-to-face interactions.

As emphasised earlier, the DCMs were not regarded as arenas for developing detailed design solutions but rather for continuous confirmation of previously established courses of action on the expected *lacks of clarity*, establishing the unexpected *lacks of clarity*, and *co-projecting* courses of actions for their resolution. In this respect, although occasionally discussions included some technically detailed conversations, this general orientation of the DCMs was largely respected by the participants.

Investigation of the personal notes taken by the participants of the design team revealed that they actively bridged the interdisciplinary discussions with their personal perspectives of what was expected, what was unexpected, what needed to be recollected and what the possible futures were. Participants of DCMs extensively took notes on each item that was discussed during the meetings in relation with *notification of what was lacking*, *collective recollection of the past* and *co-projection* of what to do next. It was observed that the notes taken by the members of the design team did not completely overlap with the *collectively noticed*, *recollected* and *co-projected* elements during discussions. Personal notes that were taken mostly reflected the discipline-specific perspective on the discussed issues, whereas the discussions were the outcome of an interdisciplinary joint effort and did not include the details of discipline-specific perspectives as written in personal notes.

For example, one of the representatives of the M&E sub-contractor typically opened the DCM agenda on his computer as an MS Excel table, and used colour coding and a column for taking notes during the DCMs. He marked the significance of each issue for him by highlighting each agenda point with green, yellow or red (reflecting importance/urgency). After each discussion, he took brief notes about what he thought was important to *notice*, *recollect* and *project* according to his discipline-specific perspective. His colour codes and notes appeared as his inferences from the discussion, and did not necessarily overlap with what he said during the discussion. For instance, his personal notes included names of the people that needed to be contacted with specific tasks such as "*Talk to John about the updated occupancy rates, update the calculations!*" whereas this information would not be shared with the others in the discussion of the effects of the new occupancy rates published by the client. Similarly, the representative of the M&E consultant continuously took notes regarding the issues to be discussed with the client based upon the *co-projected* futures in the DCMs, but the information in her notes were not always exactly same as what was explicitly discussed.

These observations revealed that the participants of the DCMs had an appreciation of the appropriate level of information and detail for the discussions held in DCMs. The discussions were directed towards a *co-projected future* about what needed to be done as an action strategy rather than detailed step-by-step instructions of what needed to be done by each participant. Participants made personal inferences based on the discussions and further *noticed*, *recollected* and *projected* what was relevant for their discipline-specific work.

4.3.2.2. Coordination workshops in the EduBuild Project

Three coordination workshops were observed in the EduBuild project. These meetings were much more focused in their scope and content compared to the DCMs. These workshops were typically named after the categories of issues they aimed to coordinate, such as an audio-visual equipment coordination workshop, or atrium servicing strategy workshop etc. In the observed coordination workshops, printed paper drawings and other design documents were heavily used during the discussion of the issues to point at specific parts of the design and to scrutinize specific aspects of the issues that were discussed. The paper-based design documents (e.g. drawings, schedules) were the centre of the discussions most of the time in the observed coordination workshops. Hand sketches, hand notes on the printed drawings, and notes on the open digital models were created during these meetings. The discussions were directed towards making some design decisions and scrutinising their details (rather than developing action strategies) with the participation of the relevant parties, and then further developing and documenting the design in the separate company offices accordingly. These meetings were generally organised when it had been thought i) that a specific design package, area or issue involved several aspects or issues that needed to be handled through a separate meeting; and/or ii) that it was the correct time in the design process to take detailed decisions regarding a specific design package, area or issue. When these preconditions were present, practitioners tended to hold these coordination workshops with the participation of all relevant parties to make the required decisions about specific parts of the design. For the purposes of this thesis, a wide range of area- or issue-specific coordination activities are categorised as coordination workshops as they had significant commonalities regarding the level of detail employed and the strategies used in these meetings. However, it should be emphasized that the researcher had the chance to observe only three such meetings out of tens of them with differing agendas. Consequently, although such categorisation can be justified for the purposes of this thesis, for other purposes such categorisation may be misleading.

The first of the observed coordination workshops was between the representatives of the M&E consultant and M&E sub-contractor. It took place at the initial stages of the observation period when the revisions of the schematic designs were not yet completed by the M&E sub-contractor after a major design change ordered by the client. The meeting mainly included questions from the representatives of the M&E sub-contractor regarding certain areas of the design that were frequently discussed in the previous DCMs. The questions posed by the representatives of the M&E sub-contractor aimed to explore the rational and background of the previously established design. The M&E sub-contractor joined the design team after the initial phases of the design. Therefore, the representatives of the M&E sub-contractor had problems with grasping the issues discussed in the DCMs and their significance. Often in the DCMs, they asked questions to the representatives of the M&E consultant and architect regarding the 'design rationale' behind the initially taken design decisions to *establish what was lacking clarity* and what the issue was. During the meeting, the representative of the M&E consultant typically answered the questions by providing a narrative regarding how and why a specific issue or area of the design had been developed the way it was. However, occasionally the representative of the M&E consultant stated that they did not develop the design to the degree she could answer to the question asked. In some instances, other disciplines were required to help answering the questions as the explanation of the representative of the M&E consultant included some obscure points regarding the judgements and decisions that had led to the current situation. For example, when the issue about wooden ceilings was being discussed (see Event EE 1), the architect was needed to complement the history of the design regarding the board rooms.

Although previously developed design by the M&E consultant was handed to the M&E sub-contractor for further detailing and site installations, this meeting evidenced that the handing of the design documents was not enough for the M&E sub-contractor to proceed with the design. The representatives of the M&E sub-contractor had *a sense of what was lacking clarity* in some parts of the M&E design but could not establish precisely without *collective recollection of the past* with the M&E consultant. They needed access to wider background of the design such as the rationales and stories behind the previously developed design, and the actors that played part in forming them. Yet the representative of the M&E consultant could not give direct answers to most of the questions and directed the representatives of the M&E sub-contractor to a larger pool of *shared past* that included other members of the design team and specific design archives. Nevertheless, the direction provided by the representative of the M&E consultant was appreciated and noted by the representatives of the M&E sub-contractor, as they deemed the access to further relevant resources about the past important in establishing *what was lacking clarity,* and how issues could be resolved in harmony with the rest of the design. In this respect, *co-projected future* was a further exploration of the *shared past* as the future actions largely depended on the *shared past*.

The other two coordination workshops that were observed, were the first and second audio-visual (AV) equipment coordination workshops. The design team in the EduBuild project took the decision of holding AV equipment coordination workshops due to the problems associated with the site installation of the AV equipment in the Phase 1 project, because of the lack of coordination at earlier stages. Representatives from the client, AV specialist sub-contractor, M&E sub-contractor, main contractor, and architect attended the first meeting and addressed the spaces that would be equipped with AV equipment one by one. A booklet with room-based distribution of the AV equipment was prepared by the AV sub-contractor before the meeting.

The meeting started with deciding how to proceed systematically during the meeting so that all the rooms with AV equipment could be considered in a reasonable amount of time. The participants decided to go over the spaces floor by floor, and on each floor, according to the types of the rooms as categorised in the booklet. Typically, for each space, the positions of the equipment were discussed and marked on 2D drawings by the AV project manager of the M&E sub-contractor. At the beginning of the meeting, each piece of AV equipment was discussed in terms of its size, fixing details, types of electric and data connections it needed, and so on. However, once the participants familiarised themselves with the main types of equipment and their fixture and service (i.e. electrical and data) requirements, towards the middle of the meeting, the discussions regarding the properties of the equipment faded out. At the beginning of the meeting, body gestures, hand sketches, photographs, and references to the Phase 1 project extensively took place to create a common picture about the types of the equipment that would be installed. Furthermore, at the beginning of the meeting, the representatives of the AV sub-contractor were very active to describe the equipment and comment about alternative types of equipment that could be provided but towards the middle of the meeting; such explanations were not as much needed anymore. In summary, the unit time spent per room considerably decreased with the progressing meeting.

For each of the discussed rooms, the representative of the M&E sub-contractor measured distances with a ruler from the 2D drawings and marked the agreed installation places of the equipment and specific comments on the drawings with a red pen. Other participants who attended the discussions provided specific information relevant to the installation of equipment to specific locations in the rooms. For example, for one of the rooms where wall mounted speakers were proposed, the representative of the architect stated that three of the walls of that room were glass. Additionally, in many other instances the representatives of the architect provided information regarding the ceiling type and ceiling height to inform the decision about the exact location of the projector. Similarly, mechanical and electrical engineers from the M&E sub-contractor were occasionally involved in the discussions to inform other participants about the locations of ventilation holes and trench heating systems.

The focus and the strategies employed in this meeting were different than the ones described previously. The aim of the meeting and the task that had to be undertaken were very clear. The equipment that would be placed had been specified by the client according to the types of rooms (e.g. classroom, office, and so on); the AV sub-contractor had created detailed lists of equipment according to the specification and the task was about *notification* of the particularities of each equipment and space in order to decide the most suitable location for the installation. Therefore, the types of discussions were not about action strategies or potential implications of the possible courses of actions, but more about the details of the design solutions. Within the ongoing flow of design, *shared past* in the form of previous design strategies, documents and knowledge were brought into the meeting by different stakeholders and jointly employed in order to assess a wide range of criteria when deciding the precise locations of the equipment. Additionally, the decisions that were taken in the meeting were noted by the representatives of the architect, M&E sub-contractor, main contractor and client in order to inform further stages of design. The degree of effort changed during the course of the meeting. This was evident in the changed rhythm of the meeting. At the beginning, a procedure to follow was set and this allowed repetitive patterns of *notification*, *recollection of the pasts* and *co-projection of future*. Until these patterns were practiced enough, the unit time spent per room was considerably more than the unit time spent towards the middle of the meeting. Implicit agreements were established among the participants of the meeting about i) in which order things should be considered in a room; ii) the potential issues that need to be considered in a particular type of room; iii) whose role was to think about what; iv) who was responsible for providing what information in order to advance the AV equipment design. This revealed a pattern of thinking in the development of the AV equipment design. This observation suggested that the members of the design team deal with numerous design instances of similar nature through reproducible patterns of *notification*, *recollection* and *co-projection*.

The third observed meeting was mainly a follow-up coordination workshop of the first AV equipment coordination workshop. The name of the workshop was 'FF&E and Electrical Implications' (FF&E – Furniture, Fixtures and Equipment). It was held two months after the first AV Equipment coordination workshop. The AV specialist sub-contractor and the AV project manager of the M&E sub-contractor developed the design to incorporate AV equipment installation details that were decided in the previous workshop. However, another coordination workshop was organised mainly for three reasons. First, some issues that could not be foreseen during the first workshop were raised while developing the detailed design, and these needed to be discussed with the representatives of the architect. Second, some installation details and locations were disputed and it was decided to resolve them through a face-to-face meeting. Third, the AV equipment design needed to be re-confirmed in the light of the many other developing aspects of the design. Consequently, in this workshop, not all the rooms with the AV equipment were covered. The previous workshop established the general principles and needs of the AV equipment installation, whereas a second workshop was needed to discuss the raised issues and the confirmation of the ongoing assumptions and progress.

This meeting was mainly concerned with two kinds of activity. First, raising the *lacks of clarity* that had surfaced since the previous AV equipment coordination workshop. These could not be captured in the previous meeting mainly due to the lacking details at the time of the initial exercise. The M&E sub-contractor only gradually realised these issues after it started to create the detailed AV equipment design according to the discussions held in the first coordination workshop. Therefore, the agenda of the meeting included some very specific points to be resolved through raising *what was lacking clarity*, *recollection of the multiple relevant pasts* and *co-projection of the future*. Discussions about these specific issues included many references to the previous workshop and previous e-mail correspondence regarding AV equipment installation. Second, it had been two months since the first workshop was held and the M&E sub-contractor wanted to discuss the AV design developed so far with the architect, and confirm that the design assumptions made and design rationale established at the first workshop still stood. This again implied many references to the first workshop. Furthermore, AV equipment installations needed to be scrutinised considering various building systems (i.e. architectural and electrical) in the light of the newly available up-to-date design which had changed since the previous meeting. For example, when the M&E sub-contractor noticed that he had been working on an old version of architectural drawings, a series of collective *notification of lacks of clarity*, *recollection of multiple pasts,* and *co-projection of future* took place to establish what needed to be changed in this new situation, and how that could be done.

Occasionally, decisions needed to be made about specific design issues that required very detailed design information, such as the exact locations of the furniture in the rooms. This information was lacking at that stage of the design. In such cases, design strategies for various aspects of the building were used to develop assumptions about the unknowns and to proceed with the AV equipment installation design. More specifically, in such cases, previously established design principles for the AV equipment installation merged with the previously established design principles of the electrical, mechanical, and architectural systems. In these occasions, *co-projection* included developing assumptions for enabling further detailing of the AV equipment design as well as establishing future contact points to check the validity of assumptions.

4.3.3. Orientation of the interdisciplinary design meetings in the OffiBuild project

The OffiBuild project was observed from the end of the conceptual design stage (i.e. beginning of the RIBA Stage D) to the beginning of the detailed design stage (i.e. end of the RIBA Stage E). Weekly DCMs that were observed during this period were the main face-to-face contact points regarding the development of the design. Although towards the end of the observation period there were discussions about initiating more-focused design meetings (i.e. like the coordination workshops that were held in the EduBuild project) to extensively discuss specific areas of the design, no such meeting took place during the observation period. Therefore, DCMs in the OffiBuild project hosted discussions that involved a wide range of considerations that the design team needed to address including, but not limited to, legal submissions, design exploration and development (e.g. architectural, structural, M&E, landscaping systems etc.), cost plan refinement, and so on. DCMs of the OffiBuild project were organised weekly and generally took much longer (i.e. 3-3.5 hours in average) than the DCMs that were held in the EduBuild project, which in average took about 1 - 1.5 hours.

While the design moved from the beginning of the RIBA Stage D towards the end of the RIBA Stage E, the nature of DCMs also changed accordingly. More specifically, developing the design involved shifts in focus of attention of the members of the design team from building-systems level to system-components levels. This meant that the kinds of *lacks of clarity*, the significance of *the shared past,* and kinds of *co-projected* courses of action exhibited gradual changes during the observation period. Nevertheless, there was also an overarching exploratory orientation in all the observed DCMs of the OffiBuild project, which mostly did not exist in the DCMs of the EduBuild project.

Although a gradual shift occurred in the focus of attention from building-systems level discussions to system-components level discussions, the exploratory orientation of the DCMs of the OffiBuild project remained during the whole observation period. Indeed, towards the end of the observation period such orientation was occasionally criticised by the bid manager of the main contractor as wasting time with unnecessary re-visits to previously-established design and design strategies. This gradual shift also correlated with the increasing references made to specific design documents (e.g. detailed drawings, section drawings etc.) where the component level designs were developed over time.

4.3.3.1. Design Coordination Meetings

The main difference between the general orientations of the DCMs in the EduBuild project and OffiBuild project can be explained through a general comparison of how the members of the design teams *noticed what was lacking clarity*, and how they chose to handle them through different approaches. In the EduBuild project, what were *notified* as *issues lacking clarity* largely depended on the previously-developed design, and already-established design processes. More specifically, the points that were at odds with the previously-established design, or that could not be handled through following the previously-established design strategies and processes, implied obstructions in further detailing a part of the design; and therefore, were *noticed as lacking clarity*. Consequently, in the EduBuild Project, the *recollection of the past* involved a significant amount of references to the *shared past* of the members of the design team both for the exploration of the *noticed lack of clarity* and its resolution. In this respect, the *co-projection* of what needed to be done for the resolution of the *lacks of clarity* heavily relied on the existing detailed design, previously-established high-level design strategies, design processes, and practicalities of the detailed design stage which significantly restricted the space of solutions (e.g. as evidenced in Event EE 4).

On the other hand, in the OffiBuild project, the period of observation involved early development of design which included the formation of high-level design strategies, design procedures, and pinning down the design from the level of building-systems to the level of system-components. The absence of previously-established details about the design, system-level design strategies, and design processes implied '*an effort to seek what was* *lacking clarity to make better informed decisions'*. In practice, this meant employment of as many perspectives as possible to extend the scope of search for revealing as many *lacks of clarity* as possible around design alternatives. This contrasted with *'an effort to establish the obstructions to clear them'* as observed in the DCMs of the EduBuild project. In this respect, in the OffiBuild project, *collective recollection of the past(s)* were mostly based upon individual professional expertise and experiences in different disciplines, and aimed to reveal as many points as possible that were *lacking clarity* within the context of the OffiBuild project. *Recollection of the past* was collective in the sense that each perspective (that was adopted by a representative of a discipline) revealed a distinct set of considerations for a design alternative which triggered further episodes of *notification* and *recollection* by the practitioners from other disciplines.

DCMs of both projects were mainly directed towards *co-projection* of action strategies that were developed upon *notification of what was lacking clarity* and *collective recollection of the relevant pasts*. However, the problem-solving orientation of the DCMs in the EduBuild project and the exploratory orientation of the DCMs in the OffiBuild project not only implied differences in the processes of *notification* and *recollection* but also in *co-projection*. More specifically, while the DCMs of the EduBuild project were directed towards the resolution of the established issues as soon as possible, the DCMs of the OffiBuild project were directed towards gradually developing many aspects of design with the consideration of as many perspectives as possible. This meant that the aims of the DCMs, and therefore the kinds of *co-projected futures*, were different in the EduBuild and OffiBuild projects. This was implied in different agenda structures of the EduBuild and OffiBuild project: there was no established agenda structure for the DCMs of the OffiBuild project until the last month of the observation period.

The agenda of the EduBuild DCMs was structured in a way that assured that all the *noticed lacks of clarity* were coped with and resolved as soon as possible. The problem-solving orientation of the DCMs of the EduBuild project was reflected both on its agenda structure and the different amounts of effort spent by the participants on the expected and unexpected *lacks of clarity*. Whereas in the OffiBuild project, especially during the first 6 months of the observation period, the agendas of DCMs and the efforts spent by the participants were mainly framed around formal or informal design milestones, such as the release of sub-contractor packages for market testing, submission of the (initial) room data sheets to the client's team, submission of the planning application to the city council, and completion of pre-defined design stages (e.g. RIBA Stage D). These design milestones were mostly defined by the associated sets of design documents that were intended to be delivered for each milestone. Therefore, design development efforts (and interdisciplinary efforts and DCMs) were organised according to these milestones. More specifically, the design team used the document-delivery requirements of these milestones as opportunities for exploration of a wide range of issues from several perspectives. In this respect, both the documented design and design strategies (including building-systems level design decisions) gradually built up, and led to a more detailed, components-level design towards the end of the observation period.

Until the beginning of the RIBA Stage E, the focus was mostly on specifying the building-systems-level design without spending much time on the detailed considerations of the system-components. During this period, the effort to seek *lacks of clarity* in the DCMs of the OffiBuild project implied that all design development propositions, alternatives and decisions aimed to be challenged from as many perspectives as possible. Therefore, until the beginning of the RIBA Stage E, in all discussions, contributions from multiple disciplines were desired, and even explicitly encouraged by the design manager of the main contractor, to increase the number of the employed perspectives, thus, enhancing the rigour of exploration.

Therefore, until the beginning of the RIBA Stage E, the discussions that took place in the DCMs could mainly be characterised as *discipline-based collective recollection of the past*. Since the *shared past* was limited, statements were mostly based on individual professional experiences. Distinct perspectives of different disciplines relied on expertise and experience with the proposed building systems, design strategies and design decisions. Various members of the design team aimed to establish the significance of design alternatives from various perspectives in the light of their expertise, experience, and the particularities of the OffiBuild project as established at the conceptual design stage. These discussions involved various disciplines continuously *noticing lacks of clarity* and *recollecting their professional pasts* to establish potential significances of design alternatives in the context of the particularities of the OffiBuild project. This resulted in numerous 'jumps' during discussions between various building systems and the perspectives that were being explored concurrently.

The congruence with the client brief, city council's planning department's informal feedbacks, cost target, and conceptual design were dominant considerations during the discussions at the earlier stages of the observation period, but other considerations such as functional aspects of different building system configurations, procurement, installation, and inter-relations between different building systems (e.g. ventilation strategy and louvres on the curtain wall system) were also articulated to explore the potential important implications of design alternatives. It is in this sense that there was an ongoing effort to seek *what was lacking clarity* about the discussed elements of the design. Each perspective about a design element (i.e. roof, windows, landscaping etc.) revealed new points that needed to be considered and *clarified,* before committing to a particular design alternative.

For example, 'the roof' could be a discussion topic that takes an hour of discussion, to consider the roof drainage strategy, the M&E equipment installation on the roof, access to roof, structural system of the roof, and so on. One of these episodes of discussions is presented below as an event (OE 1) to exemplify their unfolding and exploratory character.

Project OffiBuild – Event 1 (OE 1) – Exploration of the curtain wall system

> *The conceptual design of the OffiBuild project included one ground, one mezzanine and two upper floors. The main entrance of the building was planned to be at the main road side for easy access, and the back of the building was planned to face the canal which was behind the site. The OffiBuild project was the first building that would be built as part of a larger development scheme, and therefore there was flexibility about the positioning of the building. The front site of the building was planned to have a curtain wall system. The curtain wall system was planned to span from the ground level to the first-floor level which was in total longer than 7m. In one of the observed DCMs, within the first month of the observation period, the curtain wall system began to be discussed considering a wide variety of points related to its design, construction, and operation. Alternative frame structures of different curtain wall systems were negotiated from the transportation and installation points of view (i.e. the length and assembly of the elements as well as fixture details of the system); the visibility of the mezzanine level floor slab edge was discussed considering that the thickness of the mezzanine slab would be exposed to the outside of the building; the city council's planning department's views on such systems was discussed; the congruence between the conceptual design philosophy and the alternatives was considered; the cost of different possible system configurations were negotiated; the aesthetics of different frame layout alternatives were discussed; the maintenance of the system was considered; whether blinds or tinting would be used was negotiated, together with the considerations about the colour of the glass of the curtain wall*

system and rest of the windows; and also the effects of the curtain wall system on the ventilation strategy were discussed. During the discussion about the ventilation strategy and the curtain wall system, the number and positions of louvres and doors were part of the negotiation. The consideration of number and positions of the doors considered the fire strategy and the connection of the OffiBuild with future buildings that would be built as part of the same development scheme. The position of the main entrance and other entrances considered the potential positions of the future buildings. This also led the meeting participants to talk about the type and size of the doors and eventually the size of the main entrance door and hall, and reception desk accordingly. The discussion about the size of the main entrance door and whether a turning door would be suitable (i.e. considering the free area required at the reception area) followed the previous discussions, and the considerations about the size of the turning door also led to further discussions regarding the energy feeding system of the turning door: whether it would be a pushing turning door or electrically powered turning door.

In these respects, before the RIBA Stage E, *notification of what was lacking clarity*, *recollection of the past* and *co-projection* of what needed to be done were much less specific than they were in the DCMs of the Edubuild project. The variety of the considered issues in these almost open-ended discussions required the bid manager or the design manager from the main contractor to act as the moderator most of the time, and to converge the various discussed considerations to create some action points for the members of the design team (*co-projection of future*). These actions were generally related to gathering/documenting the information needed to further explore the discussed alternatives from multi-perspectives (e.g. cost, BREEAM points etc.) within the context of the OffiBuild project. Documentation requirements of the formal and informal design milestones were used to converge these discussions into tangible action points for various members of the design team. This implied that design-development efforts were driven by set design milestones, but the details of what was needed to be done next, depended on the discussions held during the DCMs. It is in this sense that the future was '*co-projected*' before the RIBA Stage E in the OffiBuild project.

Moreover, organisation of design around the documentation requirements of design milestones also determined the appropriate level of detail that would be considered for the discussed issues. Different members of the design team discussed and developed the design with the ultimate aim of taking the design to the level required by these milestones. The document lists (e.g. planning submission documents list, documents needed for market testing the design, RIBA Stage D documents list etc.), BREEAM credits lists, and so on, were used to assign tasks, create checklists, and survey the design progression ensuring that the progress was in line with the requirements. In this respect, the levels of detail of the *noticed lacks of clarity*, *recollected pasts*, and *co-projected courses of actions* were in line with the levels of detail required by the design milestones that drove the design development efforts. For example, often the team established limits for the exploration and negotiations, by considering that a particular level of detail or type of information under investigation would be supplied by specialist sub-contractors. This showed that the members of the design team made sense of their tasks with a view of design as an ongoing process; and prioritised their work around the milestones that were set along this process and their respective documentation requirements.

Nevertheless, a problematic aspect of organising interdisciplinary effort around formal and informal milestones was observed. Organisation of interdisciplinary effort around the documentation requirements of milestones (i.e. planning submission, market testing, design development itself etc.) sometimes created gaps between different disciplines in the development paths of design. More specifically, if a part of the design was not required to be documented as part of a milestone, then lack of development in that area could go unnoticed until problems were experienced in developing a dependent part of the design. Similarly, when the perceived levels of development anticipated by the documentation requirements were different among the members of the design team, incompatible levels of design development could occur in interdependent areas of design. Event 2 (OE 2) described below exposes one such event and how it was handled.

Project OffiBuild – Event 2 – (OE 2) Landscape surveys, design and external lighting design

> *One of the required documents for the planning application submission to the city council's planning department was the external lighting strategy for the building. This was a document that should have been coordinated by the landscape architect and M&E consultant. However, there was not an assigned landscape architect for the project from the beginning. The requirements of the planning application regarding the landscaping had been discussed in DCMs especially between the architect and the main contractor. The main contractor asked the architect to deliver the initial landscape design which was required for the planning application but the architect was reluctant as although there were landscape architects in their office, this was*

not part of their initially agreed scope of design. After these discussions, and with the pressure of the approaching planning application submission date, an initial landscape design was finally agreed to be performed by the architect. However, this was not a contracted or detailed piece of work, and showed only the general philosophy of the landscaping which was thought to be adequate for the planning application. In one of the DCMs close to the planning application submission, the M&E consultant was asked whether the external lighting strategy document was ready. Following this, the M&E consultant claimed that they had been waiting for the landscaping design to be completed, as they needed some degree of confidence about the landscaping design, before preparing an external lighting strategy for the planning application submission. Although, there were some agreed points about the external lighting strategy such as lighting of the external columns etc., the M&E consultant needed a landscaping design with topographic data to produce and confirm the external lighting strategy with some degree of confidence. As the details required by the M&E consultant were not in the landscaping design at that time, it was discussed whether the existing master plans that showed hard/soft landscaping, pavements etc. could be used to come up with an external lighting strategy. The M&E consultant asked whether the design team had the topographic data of the construction site and the surrounding area. The architect answered that the laser-scan-survey for the existing building and the site of the new build was completed but they were not in the 'information model' but separate at that moment. Therefore, it was not possible to see the building model in reference to the real topographic data collected through the laser-scan-survey. This meant that the information model would not be helpful in developing the external lighting strategy. The M&E consultant then asked the architect to send the laser-scan-survey data, and also asked for the master plans of the area; and stated that they would see what they could do with the information in hand by the following meeting.

Formal and informal design milestones provided general orientation for the organisation of interdisciplinary efforts in general as well as for the organisation of DCMs, through their corresponding documentation requirements. However, often, these were not sufficient to establish the agenda of the subsequent DCM which was mainly based on the answers to the questions such as "What are you doing next?", "What do you need in order to produce the design documents that you are planning to work on next?", "Where are you with the specifications and drawings?" and so on. This means that until the late stages of the observation period of the OffiBuild project, a *progression-oriented co-projection* was present, in contrast to a *problem-resolution oriented co-projection*, which was observed in the EduBuild project. In the OffiBuild project, it was only towards the end of the observation period that a standard format for the minutes and agenda of DCMs was issued to capture specific design issues that needed to be resolved.

The milestones that followed the planning application submission and completion of the RIBA Stage D required increasingly detailed documentation of the design, which resulted in a gradual shift in the focus of efforts in DCMs. More discussions started to be held about specific parts of the building (e.g. reception area) and specific components of the building systems (e.g. slab edge details). Therefore, the discussions that were held in DCMs after the completion of the RIBA Stage D were increasingly directed towards *notification* and resolution of coordination requirements among various members of the design team for the component level design of various building systems. This was different than the previous main orientation that was directed towards challenging the design from as many perspectives as possible and sought for *lacks of clarity*. Nevertheless, previously-made design strategies and decisions had still been occasionally re-visited and challenged, especially when the members of the design team struggled to find component-level design solutions that could satisfy all the disciplines involved. This shift in the focus of efforts was also reflected on the number of participants in DCMs, which significantly decreased over time. The participants were mostly stabilised to the core design disciplines (i.e. representatives from the architect, structural engineering consultancy, M&E engineering consultancy, client project manager (PM) and design and costing team from the main contractor) short after the submission of the planning application documents.

Therefore, the orientation of the DCMs that were observed after the completion of the RIBA Stage D involved challenging, and sometimes changing, the previously-established design strategies and decisions, and the identification of specific coordination requirements and their resolution. During this period, previously-established design -and the assumptions upon which it was based- were still challenged in the light of increasing level of detail and interdisciplinary coordination issues. However, at the same time, previously-established design was also used as a sufficiently stable starting point for identifying interdisciplinary coordination requirements and issues, and for further development of design through their discussion. In this respect, during the RIBA Stage E of the OffiBuild project, noticeable *lacks of clarity* could be about i) high-level design strategies and principles; and ii) specific interdisciplinary coordination issues in designing specific parts of the building. Nevertheless, the main orientation was still not on problem-solving as it was in the EduBuild project. Even when the focus was on more-detailed aspects of the design, the efforts were mostly about exploration of the coordination requirements and issues rather than identification, exploration and resolution of problems. In this respect, although there was not an effort to push as many perspectives as possible in discussions anymore (as it happened during the earlier stages of the observation period), the main *exploratory* orientation was still in place even at the later stages of the observation period.

After the submission of the planning application, whenever a specific set of documents were uploaded or updated in the online document management system, the design team explored them both visually and discursively to understand the assumptions embedded in that part of the design as well as the level of development presented in those documents. These took long hours of inspection of the developing design during DCMs accompanied by discussions around the inspected parts of the design. These inspections were directed towards the *notification* of what needed to be coordinated among various members of the design team while designing the details of specific parts of the building. Although almost all the published design documents were aimed to be discussed during DCMs in the RIBA Stage E, considerably more effort was spent on discussing the unconventional and irregular parts of the design.

For example, although the general structural system of the building was reinforced concrete frame, there was a so called 'meeting core' at one side of the atrium that spanned from ground level to the top level. This meeting core was planned to be structurally supported by a steel framing system (SFS). Different aspects of this part remained as a significant source of design related discussions as it needed to be separately considered functionally, architecturally and structurally to ensure that this part of the building was integrated with the wider systems of the building. For example, all the following issues needed to be discussed at length by the design team during DCMS: the ventilation strategy for the meeting core -whether the extracted air would be pumped in the atrium or in the ducts, and the acoustic implications of these options-; the shape of the concrete columns that crossed the meeting core and the potential implications of changing them with circular columns for better aesthetics; shape of the windows at this oval shaped meeting core and the potential implications of having circular windows on the walls of the meeting core; integration of the M&E services of the meeting core with the other parts of the building.

During these discussions in the RIBA Stage E, previous design decisions that formed the basis for further development needed to be *collectively recollected* and revisited. Stories and reasoning governing previous decisions were re-articulated to take further decisions. This was similar to the pattern of *collective recollection* of the past that was observed in the EduBuild project. For example, the decision about having aluminium windows instead of UPVC ones and having suspended ceilings at the atrium were previously agreed decisions but in one of the DCMs the design manager from the main contractor raised the question about why they decided on these. The basis of these previous decisions was needed to be *collectively recollected* to make further design decisions that were compatible with previous assumptions, strategies and decisions related to the type of material of windows and ceiling types in the atrium. At this stage in the OffiBuild project, there were further instances that showed the significance of the *shared past* to proceed with the design. For example, at the beginning of the RIBA Stage E, representatives of the M&E consultant stopped attending DCMs without providing an explanation. After having a couple of DCMs without an M&E consultant, the main contractor brought a mechanical engineer from their own company to control the M&E design until an M&E sub-contractor was assigned to the project. Although the Stage D documents were in the online document management system, that engineer stated that he needed to visit the previous consultant "*just to see how they thought*". The need to witness the *shared past* was also apparent from the fact that the site manager of the main contractor started to attend DCMs almost 4 months prior to the start of the construction works. This was justified by the design manager of the main contractor who stated that the site manager needed to familiarise himself with the design to appreciate the design intent before the works on the site start.

On the other hand, the extent of *recollection of the past* needed to be adjusted to the progressing design. This meant that, at the RIBA Stage E, when the design team spent a long time with challenging previously-developed building-system-level strategies or design principles, either the design manager or the bid manager of the main contractor stopped the discussion, reminding the changing needs of interdisciplinary work. For example, when the ventilation, cooling, and duct and pipe work of the meeting core was discussed for a considerably long time in a DCM at the RIBA Stage E, the design manager of the main contractor stated that all these issues were documented in Stage D, and strategies were created for them; and therefore, they did not need to "*reinvent the wheel*".

During the RIBA Stage E, *co-projections* of what were needed to be done started to shift towards the situation observed in the EduBuild project. At the beginning of the RIBA Stage E design team started to talk about keeping the minutes of the DCMs. It was proposed to have two sections like the standard minutes/agenda form used in the EduBuild project. One section was proposed to be about the key issues raised during the DCM and other about the specific information requirements of different parties. This structure was very similar to the one used in the EduBuild project. However, keeping meeting minutes and using them as the agenda of the following meeting only started weeks after they were first proposed, and the researcher could observe only one meeting with an agenda with the described structure.

Meanwhile what was needed to be done to progress with the design was mainly driven by the responsibilities assigned in the Information Requirement Schedule (IRS), which was a responsibility matrix developed by the design manager of the main contractor for the delivery of design documents for the RIBA Stage E. IRS assigned the documents that were required to be delivered to various stakeholders of the design team. IRS also included delivery deadlines for each of the documents listed in it and a column to take notes regarding the delivery of each of the listed documents. A note could be, for example, a pre-requisite for starting the preparation of the document or a decision that had been waited before proceeding with the preparation of a document. The responsibilities and deadlines assigned through the IRS, and the notes taken on it, structured the organisation of the interdisciplinary efforts both in DCMs and in general. More specifically, who needed to do what and when, was directed based upon IRS during the RIBA Stage E. IRS was continuously re-visited and updated as a checklist and control mechanism for the development of the design during the RIBA Stage E. Various discussions that were held around the published documents (i.e. especially those related to the irregular/unconventional parts of the design) reached a certain level of closure with time. Concurrently, the number of references made to remote interactions, such as reviewing, updating, and marking-up documents, increased.

One aspect of *co-projection* at this stage of the design in the OffiBuild project was the delicately adjusted level of detail in the documents to be published. Although system-components-level drawings were the focus of the discussions and interdisciplinary efforts, a delicate balance needed to be handled between the design responsibilities of consultants and future sub-contractors. Therefore, during the RIBA Stage E, the discussions were generally based on some detailed sections and 2D drawings; however, they were not directed to closure in design development as the sub-contractors were expected to provide the final detailed design in most cases. Consequently, the transition from system-level design explorations to component-level design detailing was not a 'jump' but a smooth and gradual transition where both levels were considered and adjusted accordingly still with a wide range of considerations such as potential suppliers, cost, BREEAM credits, installation, and aesthetics. In other words, a non-linear transition from system-level explorations to more-detailed design documentation took place and this was made evident in the levels of detail required in the assigned design document delivery responsibilities.

Notification of what was lacking clarity, *recollection of the past,* and *co-projection of what were needed to be done* took another significant turn when the site project manager started to attend DCMs. The site manager did not attend the meetings as a passive observer and often contributed to discussions by providing construction-stage related perspectives. Moreover, in the last observed DCM, just before the start of the construction works on the site, the site manager stated that the site team decided to introduce weekly meetings and his role was to bridge the design and site teams to keep both teams aware of the issues raised by the other team. This showed the significant and important connection that should be managed between the ongoing site works and design in the OffiBuild project.

4.3.4. Orientation of the interdisciplinary design meetings in the LabBuild project

The LabBuild project was observed for a considerably shorter period of time (six meetings were observed in total) in comparison to the OffiBuild and EduBuild projects. However, observation of the meetings for design development offered further valuable insight due to the unique requirements of the project. First, the LabBuild was a fast-tracked project in the sense that the design and construction stages substantially overlapped, and operated concurrently. This affected the general organisation of the design process and caused the ongoing site works to have significant effects on the developing design. Second, the LabBuild project concerned the design and construction of a building that included numerous unconventional equipment and building systems. Therefore, the representatives of the client organisation were highly involved in the design process to contribute to the design with their specialist knowledge, and design and construction teams involved some specialist sub-contractors that were hired to deliver the unconventional building systems. These unconventional building systems still needed to be integrated with more traditional systems such as M&E and structural and architectural systems.

These major differences of the LabBuild project caused the interdisciplinary design efforts to be directed and distributed in a different way than the EduBuild and OffiBuild projects. More specifically, during the observation period, there was more than one major orientation for design development meetings to respond to various critical factors that drove the design. Agendas of the observed meetings were largely different from the other case studies and reflected several considerations including the progress on site, progress of design, contributions needed from the client organisation, and integration of the design of unconventional systems with the rest of the design (see Figure 7 in Section 4.2.2 for an example of agenda). In this respect, in the LabBuild project there were more regular DCMs than the other two projects. In the LabBuild project, there were two regular weekly DCMs. One of them was called the Design Team Meeting (i.e. main contractor's internal design meeting) and the other was called the Client Design Meeting which showed that the contributions of the client organisation were always critical, unlike the EduBuild and OffiBuild projects.

The observed meetings differed in their orientation (i.e. agenda structure), level of detail, profiles of participants, and the kinds of issues that were discussed. The first observed meeting was held to coordinate the set-up of Furniture, Fixture and Equipment (FF&E) in the clean rooms. The effort was mainly directed towards mutual adjustment of the design strategy of the clean room sub-contractor, special requirements of the client regarding these rooms and other building systems such as architectural and M&E systems. It is important to emphasise that there were no representatives from the structural engineering consultancy as the structural system was already mostly erected, and therefore known to the other members of the design team. The discussions during this meeting were similar to the ones in the OffiBuild project which aimed to explore the unconventional and irregular parts of the design. Participants aimed to establish coordination requirements between different disciplines through the discussions that revealed i) design strategies behind various building systems involved in the clean rooms; and ii) specific needs of the client organisation regarding the use and maintenance of the clean rooms. The meeting started with the representative of the clean room sub-contractor explaining the reasoning of their design which was based on the number and location of the openings in the room. Following this, the employees of the client organisation and the representatives of the M&E consultant began to ask questions and make comments regarding the design criteria of FF&E in the clean rooms. The client made comments about the maintenance strategy of the specialist equipment that would go in the clean rooms. The representatives of the M&E consultant asked the required degree of flexibility of the M&E system for future adaptations, for example, relocation of the power sockets. The employees of the client made assertions regarding the operational needs and the representatives of the M&E consultant took extensive notes based upon the needs of the client. The representative of the clean room sub-contractor frequently intervened in the discussion when certain design aspects of the clean rooms needed to be considered due to the special requirements of these unconventional rooms.

In this respect, *lacks of clarity* were about the design principles and criteria of various building systems, and their interfaces that would require interdisciplinary coordination. *Recollection of the past* was mainly based on professional backgrounds with a particular priority given to the perspective of the clean room sub-contractor. It was observed that the representatives of the architect and M&E sub-contractor mainly aimed to adjust their design according to the needs and particularities of the clean room sub-contractor, but not the other way around. *Co-projection* involved decisions about future courses of action in terms of developing certain design documents for further coordination, and scheduling joint coordination workshops for more-detailed coordination of specific components in these rooms. One of the discussions that took place in this meeting is presented below as an event (LE 1).

Project LabBuild - Event 1 (LE 1) – Small power outlets in the Clean Rooms

> *The clean rooms were specially constructed rooms in the laboratory. The role of the clean rooms was to accommodate sophisticated technology, and high-precision production and test equipment that would be procured and installed by the client. Consequently, the clean rooms needed to satisfy some special specifications such as the light and dust levels allowed in the rooms. There was a specialist sub-contractor that was responsible for the construction of the clean rooms. The sub-contractor had responsibility for delivering both the design and construction according to the specifications provided by the client. Due to the special materials and construction techniques that needed to be used for the construction of the clean rooms and the specialist equipment that would go into these rooms, coordination of the clean room construction between different members of the design team appeared as a separate additional coordination. One of the negotiations was about the installation of the services to feed the power sockets and switches. The M&E engineers who were responsible for the design and construction of the electrical services first wanted to learn the appropriate heights of the switches and power sockets that were needed in the room, because these were different from the other areas of the building where offices were located. In the office areas, the height and locations of these switches were based on the heights and locations of the desks, locations of the windows, doors, and columns. However, in the clean rooms, the locations of the switches and*

power sockets depended on the locations of the special equipment and the construction details of the clean rooms. Although the M&E engineer was looking for the ways to standardise the height of the sockets for the ease of construction and avoid confusion, this was not possible in all circumstances. The special needs of the special equipment and the gold coated wall panels which should not be perforated required more-detailed discussion about how the electrical services could be installed in the clean rooms. In this respect, negotiations around the installation of the small power outlets needed to be extended to the construction details of the clean rooms. The construction details, such as how the cables that enter the clean rooms could be taken out, and whether there was a ceiling void between the ceiling of the ground floor where clean rooms are located and the slab of the first floor, were questioned. In the end, it was decided that the client needed to specify the exact locations of the equipment before the other members of the design team could make precise design decisions.

In this meeting, the level of detail of the design that needed to be developed was discussed with many references to the situation of the construction on the site and the information requirements of the site team for smooth progress of the construction. The site perspective was mainly articulated by the design manager of the main contractor during this meeting.

A second design meeting was observed in the LabBuild project on the same day. Two of the agenda items of the second were about the design of the external lighting and reception area. However, the level of development of the external lighting and reception area designs were much further behind than the design of the clean rooms. External lighting and reception area were two of the parts of the design that were assigned provisional sums of money. Provisional sums were assigned to certain parts of the design to proceed quickly with the design at the beginning of the project and start the construction as soon as possible. The development of the design and coordination in these areas were left to a future time at the initial stages of the project and provisional costs were assigned to these areas because of the lack of development of the design for these areas. However, design of these areas had become a pressing issue with the construction progressing on the site and the design lacking in these areas.

In the second observed meeting, different kinds of *lacks of clarity* were noticed by different members of the design team and eventually *unrelated pasts* were *recollected* about these *lacks of clarity*. The discussions revealed that this was due to the different driving factors that various members of the design team considered. For example, when the design of external lightings was discussed, the representative of the architect complained that the initial scheme they proposed was not followed by the M&E sub-contractor so far, and that she needed the latest documents regarding external lighting design from the M&E sub-contractor to be able to proceed with the design of the external lighting. She brought photos of external light fittings and tried to "*communicate the concept*" to other members of the design team to create an integrated landscape and façade scheme. Meanwhile, the design manager of the contractor was mainly concerned with fixing the positions of the lights, mainly the location of the large illuminated sign which was planned to be placed in front of the building, so that the provisional sum of external lighting could be fixed with confidence. This caused a conflict between the design manager of the main contractor and the representative of the architect. The representative of the architect wanted to discuss the 'concept' of the scheme whereas the design manager of the contractor wanted to know the 'exact locations' of the lights. At the same time, the representative of the client organisation contributed to the conversation with the history and identity of the organisation to inspire the other members of the design team regarding the shape and position of the large illuminated sign. For the reception area, similar conflicts occurred, which revealed the variety of factors that directed the efforts of various participants of the meeting.

Therefore, during the discussions about the parts of the design that were assigned provisional sums, *noticed lacks of clarity* varied according to varying perceptions and expectations regarding the appropriate level of development of design. As a result, a significant amount of effort was spent on the appreciation of different driving factors, and the implications of these on various members of the design team. Participants largely drew on the *shared past* to justify their own positions and expectations, but individual professional pasts and expertise were also used to establish stronger positions. *Co-projection* took the form of agreed courses of action about the documents that needed to be developed, reviewed and commented upon. Therefore, the first closures of these discussions were about a joint appreciation of the level of development required at that time for the area of the design that was under consideration. Second closures were about who needed to do what to meet multiple requirements.

The other four observed meetings were about the detailed planning of the specialist equipment that would be procured by the client organisation's team using information models. Therefore, these last four observed meetings in the LabBuild project are analysed in detail in Chapter 6, in which interdisciplinary model-based working is scrutinised.

Nevertheless, some issues revealed during these four meetings were directly related to design development, and therefore are briefly presented below.

At the time of observations, it was important for the client team to have precise dimensions of various building systems because the equipment that would be procured was very expensive and had to be produced upon order. The problem was that fast-tracked design and construction prioritised the fast progress of the site works which resulted in using loosely coordinated paper-based documents primarily. Moreover, the as-built situation was not systematically fed-back into the existing design because keeping up with the fast progressing site works was the main consideration of the design team. Therefore, during these four observed meetings these situations were *noticed*; *the pasts were recollected* by several actors and from several mediums (e.g. from the site, previous paper-based drawings and previously published 3D models); and *co-projections* were performed to establish what needed to be done to re-adjust the design, site works and the client's requirements.

The efforts were mainly directed to make the documented design and site works consistent for enabling planning of the sensitive specialist laboratory equipment. This included first *notification of the lacks of clarity* by the design team based on the needs of the client organisation, and then *notification of the lacks of clarity* caused by the inconsistencies between the design and the site works. *Recollection of the past* included i) checking the contractual documents in order to see whether the design team was responsible for delivering high precision information to the client; ii) discussions between the main contractor, clean room sub-contractor, M&E sub-contractor and architect in order to evaluate the actual level of development of the design, the level of development of the issued design documents, and the level of development of the construction on the site; and finally iii) discussions in order to establish the inconsistencies between all these and the root causes of these inconsistencies. *Co-projection* included several different kinds of courses of actions including the negotiation of the level of detail in documented design, laser scanning the completed parts of the site works, re-publication of the design documents aligned with the situation on the construction site, and organisation of coordination workshops between the client team and sub-contractors that had design responsibility.

4.4. The Practical Concerns and Lived Directionality of Interdisciplinary Design Development

In the previous section, it has been shown that during the observed meetings, interdisciplinary effort was spent on a complex series of activities of *notification of lacks of clarity*, *collective recollection of multiple past(s)*, and *co-projection* of what needed to be done next. However, the findings suggest that what were deemed as i) *lacks of clarity*; ii) *relevant pasts that needed to be recollected*; and iii) *possible co-projections*, differed from project to project leading to different patterns of activities in each project (see Section 4.2.3). This section shows that despite these differences among the observed projects, some overarching 'themes of practical concerns' can be identified about interdisciplinary design development. The three 'themes of practical concerns' developed in this section provide explanations about what was it that was achieved through the ongoing performance of the activities presented in the previous sections. It is argued that the reason because the practitioners engaged in the above listed three main kinds of activities on an ongoing basis was to continuously: i) *'establish the 'familiar and unfamiliar' aspects of design project'*; ii) *'confirm, adjust, or establish interdisciplinary interfaces and design criteria'*; and iii) *'establish discipline-specific design purposes'.* At the end of this section, the overarching explanations of what 'concerned' the practitioners in interdisciplinary design development is then further refined to a theoretical explanation about the 'lived directionality' of interdisciplinary design development, which is argued to enable the practitioners to make sense of what to do, and what ought to be done in interdisciplinary design development.

First of the three overarching themes of 'practical concerns' that emerged is the '*establishment of the 'familiar and unfamiliar' aspects of design project'*. This theme was fundamental in all observed interdisciplinary design meetings and can be seen in all the events presented in this chapter. For example, Event EE 1 is about *establishing familiar and unfamiliar aspects of* having decorative wooden ceilings in the board room. Similarly, Event OE 1 is about *establishing familiar and unfamiliar aspects of* having curtain wall system for the front side of the office building. It is evident in these events that the meaning of *'familiarity'* differed from project to project, from actor to actor, and from time to time. For example, while in the EduBuild project generally the *shared past* was prominent in establishing *familiarity*, during the early stages of the OffiBuild project, individual professional pasts were more prominent. In the LabBuild project, the project was unique due to the number of specialist equipment and corresponding infrastructural requirements, and therefore high involvement of the client and specialist sub-contractors was required during the design. This signalled a high amount of *unfamiliarity* to the members of the design team. The design team set a separate weekly client DCM in order to be able to establish *unfamiliarity* stemming from the unique equipment and unconventional needs of the client. The necessity of adjustment of the site works and design works on an ongoing basis also created ongoing *unfamiliarity* that needed to be established through frequent site visits. This showed that, in the LabBuild project, the meaning of *'familiarity'* depended not only on the professional and *shared pasts* in design development but also on the situation of the site works. More specifically, the implications of the erected parts of the building on the design development needed to be continuously established as *familiar* or *unfamiliar* in order to be able to proceed with the design development.

To sum up the above, in the observed projects, the design was a work in progress, and therefore the future of the design was always unknown to a certain degree to the members of the design team. Nevertheless, ambiguity was expected and even desired especially during the earlier stages of the design. What mattered more to practitioners was to establish whether the kinds of ambiguities and unknowns were *familiar*. The *familiar* (i.e. expected and regular*)* unknowns and ambiguities that were encountered did not get much attention since the practitioners knew how to work with them in developing the design. On the other hand, coping with the *unfamiliar* (unexpected and irregular) unknowns and ambiguities required much more time and effort in interdisciplinary meetings for design development (e.g. Events EE 1, EE 2, LE 1, and the design of the meeting core and roof in the OffiBuild project). The meaning of '*familiarity*' continuously changed, depending on the unfolding particulars of design project, and was continuously re-defined based on a number of resources such as professional pasts, *shared pasts* of the practitioners, and foreseeable implications of the site works on design development. As a result, an ongoing joint evaluation of *familiar* and *unfamiliar* aspects of design project was made to adjust interdisciplinary efforts and spend appropriate effort on design issues according to their *familiarity*.

Establishing *familiar* and *unfamiliar* was a joint undertaking of various members of the design team because the meanings of '*familiar*' and '*unfamiliar*' did not depend on the proposed building systems and design solutions *per se*. For example, in Event OE 1, the design team aimed to establish *familiar* and *unfamiliar* by holding a discussion around the curtain wall system and employing many different perspectives. This discussion revealed interfaces and design criteria for the curtain wall system such as the slab thickness of the mezzanine floor, and the connection between the ventilation strategy and the curtain wall system. Curtain wall system *per se* was a *familiar* system for all the disciplines involved. However, Event OE 1 shows that it exhibited some *unfamiliar* aspects within the context of the OffiBuild project such as the aesthetic concerns that arose due to the visibility of the slab thickness of the mezzanine floor. In this case, the *unfamiliarity* that required attention was *noticed* as an effect of a relation between two systems (i.e. curtain wall system and concrete slab system). Formulation of this *unfamiliarity,* and the potential design alternatives related to it, required a joint assessment of representatives from various disciplines who expressed their discipline-specific views. In other words, the *unfamiliarity* emerged at an *interdisciplinary interface* and was described through *design criteria* (i.e. in Event OE 1 decisions about the curtain wall system and visual aspects of the slab of the mezzanine floor had to consider each other). Similar situations were also observed in, for example, Events EE 3 and LE 1 in which interacting practitioners aimed to establish the *interdisciplinary interfaces and design criteria* (e.g. colour of the air-transfer grilles in Event EE 1 and the desire of M&E sub-contractor to apply a general service strategy in Event LE 1). The design criteria reflected i) the concerns of those who perceived the interface as relevant to their discipline; ii) current stage of the design through the involvement of professional and shared pasts to varying degrees in the discussion; and iii) the breakdown of the building into various systems which enabled locating interfaces and distribute responsibilities around the interface. This meant that the *collective recollection of professional and/or shared pasts* (and situation on the site) were expressed and understood in terms of their implications on the interfaces and design criteria of different building components and systems, and therefore between various disciplines. *Familiarity* and *unfamiliarity* were qualities of these interfaces. This aspect of the findings revealed the second overarching theme of practical concerns: *re-confirmation, adjustment and re-establishment of the interdisciplinary interfaces and design criteria*.

The design entities, *per se*, had different significances for different members of the design team due to the differences in backgrounds, knowledge and foci. For instance, what an office space meant to an architect was different than what that office space meant to the electrical engineer in terms of design development. However, breaking down the design in terms of various disciplines, design stages, and building systems, created *interfaces* to which a variety of *design criteria* about design entities were assigned; and thus, highlighted interdisciplinary significances of design entities. In the observed projects, it was these *interfaces and design criteria* that enabled interdisciplinary communication among different members of the design team without having substantial access to each other's knowledge and meanings.

In this situation, the meanings were not integrated or shared, but the coordination requirements were articulated and handled through the *interfaces and the corresponding design criteria* that were based on specific combinations and uses of discipline-specific roles, design stages, and building systems. The interdisciplinary design work was organised at the *interfaces* by having a shared understanding of *interfaces and the corresponding design criteria* which enabled communication among different members of the design team. For example, although an office space meant different things to the architect and electrical engineer of the EduBuild project, they both had an understanding of what needed to be coordinated with each other at a specific stage of the design for delivering an adequate office space design. They both knew that the positions of floor electrical boxes needed to be coordinated with the planned locations of furniture at the detailed design stage. Consequently, the substance of the interdisciplinary interactions was the joint ability of the design team to consistently and coherently work through shared *interfaces and corresponding design criteria*.

In this respect, *'familiarity'* implied a shared understanding of coordination needs among various members of the design team at a given time. *Collective recollection of professional and shared pasts* re-confirmed shared understanding of coordination needs among different parties, or revealed *unfamiliar* issues around them. Expected and regular *lacks of clarity* in the EduBuild and OffiBuild projects did not require too much effort to be coordinated. In such cases, the *interfaces and design criteria* were quickly re-confirmed and the whole act was experienced as a natural part of progressing design. However, in case of presence of unexpected *lacks of clarity* in the EduBuild project or *lacks of clarity* around irregular or unconventional areas of design in the OffiBuild project, long discussions took place in order to *(re-) establish interfaces and design criteria*. For example, Events EE 1, EE 2, EE 4, OE 2, and LE 1 revealed instances of *re-establishment of interfaces and design criteria*.

Recollection of professional pasts involved standard professional practices, knowledge from experience, and formal professional guidance (e.g. documentation requirements for each pre-set stage of design such as RIBA Stage D) in given disciplines, providing a starting point to *establish interfaces and design criteria in interdisciplinary projects*. These kinds of *interfaces and design criteria* were the foundation for interdisciplinary communication. These professional pasts constituted the initial repertoires for making sense of the design, a basis for the expectations and perceived coordination requirements among different members of the design team; and thus, enabled meaningful communication. However, the design was a developing work where the design entities and their coordination needs continuously changed. The project specific coordination needs were different in each observed case, and these needs changed with the developing project. *Interfaces and criteria* needed to be continuously *re-confirmed*, *re-established*, *re-adjusted* and *maintained* over the course of the project.

In practice, handling change as a project developed was accomplished through continuous interdisciplinary discussions that enabled *notification of lacks of clarity*, *recollection of professional and shared pasts,* and *co-projection of what needed to be done next*. Ongoing discussions allowed members of the design team to appreciate others' situations, concerns, priorities and needs, and thus adjusted their understandings accordingly. As a result, design related interdisciplinary meetings had been the arena where different members of the design team either jointly *re-confirmed* the historically established coordination requirements and procedures, or *jointly developed project specific interfaces and criteria* for handling project specific or situation specific coordination requirements. In this respect, each *re-confirmation and/or establishment* became part of the *shared past*, and therefore determined what was *familiar* and what was *unfamiliar* in the subsequent events.

Members of the design teams skilfully *recollected professional and shared pasts* in order to *re-confirm or re-establish interdisciplinary interfaces and design criteria* through a changing range of interdisciplinary interactions that adapted to the changing circumstances of projects. Therefore, the range and nature of the interdisciplinary interactions were adjusted according to the presence or absence of the *confirmed or established interfaces and design criteria* around particular parts of design. For example, the coordination workshops that took place in the EduBuild project aimed to *confirm or establish interfaces and design criteria* around certain components of certain building systems. The reason these kinds of focused meetings were absent in the OffiBuild project was because the members of the design team in the OffiBuild project were busy *establishing* the building system level *interfaces and design criteria* before focusing on the *interfaces and design criteria* for the components of those systems. This is because the system level *interfaces and design criteria* provided direction for component level *interfaces and design criteria* by revealing what were *familiar* (and did not require too much interdisciplinary interaction), and what were *unfamiliar* (and needed to be discussed extensively at the component level).

A large amount of the design work was performed within disciplines without any interdisciplinary interactions between the members of the design team. The amount of the time spent on design work in each discipline was much greater than the amount of the time spent on face-to-face or remote interdisciplinary interactions. Each stakeholder had the responsibility and authority of representing a particular perspective and delivering a particular part of the design. Therefore, ultimately, the members of the design team mainly needed to have a shared understanding of *interfaces and design criteria* in order to be able to set consistent and coherent discipline-specific design purposes which would satisfy the target design criteria for the building as a whole. This argument leads to the third overarching theme of practical concerns: *establishment of discipline-specific design purposes*.

Confirmation or *establishment* of the ever-changing *interfaces and design criteria* were of primary importance for the members of the design team because *interfaces and design criteria* guided designs within each discipline. Holding discussions for *confirmation or establishment of interfaces and design criteria* did not aim to see the design from each other's perspective. These discussions rather aimed to adjust different professional perspectives to deliver coherent and consistent specific parts of design that function and satisfy the requirements of the building as a whole.

Establishment of the '*familiar*' and '*unfamiliar*', and therefore *re-confirmation or establishment of interdisciplinary interfaces and design criteria* concern the practitioners for one root reason: the need to *continuously re-establish discipline-specific purposes* according to the unfolding necessities of the developing design. More specifically, members of the design team knew what to do and what ought to be done based upon their appreciation of the *familiar* and *unfamiliar*, and the *interfaces and design criteria* around *familia*r and *unfamiliar* aspects of design. Ever-changing meaning of *familiarity* guided interdisciplinary attention and efforts toward *(re-)confirmation, (re-)adjustment,* or *(re-)establishment of interfaces and design criteria*. As a result, practitioners managed to continuously *re-establish discipline-specific design purposes*. In practice, practitioners developed their part of the design with less interdisciplinary interaction for the parts that were *familiar* to them. At the same time, they *noticed* and *established the unfamiliar*; and further *established interdisciplinary interfaces and design criteria* for the *unfamiliar* in order to coordinate the *unfamiliar* in harmony with other elements of design. The members of the design team developed *purposes* and attached meanings to design work and its social and material constituents through their interdisciplinary interactions. See Figure 8 below for a depiction of how these three themes of practical concerns enabled meaning-making in interdisciplinary design development.

Resources for meaning making / Practical concerns	Previous individual experience, professional and institutional standards of practice	Jointly constructed shared past
Establishing the familiarity of the situation	Is it familiar to have this design issue at this stage of the design, with this stakeholder, about this building part / function according to the established standards of practices and my personal experience?	Is it expected to have this design issue at this stage of the design, with this stakeholder, about this building part / function considering what happened previously in the project?
Re-confirmation or establishment of design interfaces and criteria	Do I know how to proceed with such a design issue, in this particular stage of design with this stakeholder? If yes, is the proposed way of proceeding with this issue same as the way I am used to, or I prefer to proceed with this?	Is the articulated way of proceeding with the design issue is in line with the previous ways of coordinating similar issues in this project? Is it in harmony with other related interfaces and design criteria previously confirmed / established in the project?
Establishing disciplinary design purposes	What am I supposed to do next on this design issue in order to accomplish my disciplinary work within the established standards of the profession, institutions, and my personal professional experience?	What am I supposed to do next on this design issue in order to accomplish my disciplinary work in consideration with the particularities of this project that I know about?

Figure 8 - The relation between the practical concerns and resources for meaning making

Consequently, the discussions around the design issues and progress were not necessarily held to come to a consensus but rather pursued a joint agreement on what was aimed to be achieved; that is '*a shared sense of purposefulness*'. Consequently, achieving '*a shared sense of purposefulness*' around the design issues or processes was the necessary and sufficient condition for making sense of what to do and what ought to be done in interdisciplinary design. Therefore, once a *shared sense of purposefulness* was achieved about a design issue or design process, then the *interfaces and criteria* could be critically considered, confirmed, adjusted or swapped with new ones according to the perceived requirements. In this regard, the three themes presented as 'practical concerns' played out in dynamic and complex ways resulting in series of i) *establishing familiarity*; ii) *re-confirmation, re-adjustment and re-establishment of interdisciplinary interfaces and design criteria*; and iii) *continuous development of discipline-specific design purposes*. These practical concerns were tied to each other with the ultimate purpose of providing a *shared sense of purposefulness* around the developing design and its social and material constituents.

Therefore, the 'lived directionality' of the interdisciplinary design meetings can be argued to be '*continuous re-establishment of a shared sense of purposefulness'* among the members of a design team. It is through this *shared sense of purposefulness* that various members of the design team were enabled to deliver the design in coherent and consistent parts that satisfied the target criteria for the building as a whole. Although the researcher had only access to face-to-face interdisciplinary interactions, the stated 'lived directionality' is valid for all interdisciplinary interactions because, as argued in Section 4.2, various interdisciplinary interactions enacted and referred to each other. Therefore, the stated 'lived directionality' is an overarching one that also covered the remote interactions of reviewing, marking-up, or commenting on published design documents as well as sending e-mails, talking on the phone, and so on.

4.5. Discussion and Concept Development

This chapter aims to establish how practitioners made sense of 'what to do' and 'what ought to be done' in design development by focusing on the orientation and practical concerns of the observed interdisciplinary design meetings. In this respect, the observed practices are presented as non-linear and complex series of activities involving *notification of lacks of clarity*, *recollection of professional and shared pasts,* and *co-projection of what needed to be done next*. In each of the observed projects, efforts were spent on different kinds of *noticed lacks of clarity* as a result of different project-specific *past* (events), and the issues that arose were therefore handled through different kinds of *co-projections*. These differences are explained through three overarching themes that reflected common practical concerns of the members of design teams in interdisciplinary design development. These were the concerns about:

- *establishing the 'familiar and unfamiliar' aspects of design project*;
- *re-confirmation or establishment of interdisciplinary interfaces and design criteria*;
- *establishing discipline-specific design purposes*.

These practical concerns were entangled and deeply embedded in the observed interdisciplinary discussions. As a result, they enacted a 'lived directionality' that could be described as '*continuous re-establishment of a shared sense of purposefulness*'. In the light of these arguments, how interdisciplinary design development is organised is discussed below to develop an explanatory organisational concept.

Dossick and Neff (2011: 90) argue that design projects are "*dynamic organisations of 'building in the making' where the organisation is itself being created while the building is being made*". It has been shown that this 'becoming view of organising' (i.e. as opposed to a 'being view of organisation') in projects (Cicmil & Marshall 2005) relies both i) on the established professional standards and institutions that enable a foundation for interaction among various practitioners; and ii) the unique contexts that continuously re-configure the protocols of interaction among practitioners (Cicmil & Marshall 2005; Whyte et al. 2008; Dossick & Neff 2011). The findings presented and analysed in this chapter concur with these arguments and extend them by providing an explanation of the process of becoming (i.e. organising) which jointly considers the established and the emergent resources for meaning making in interactions.

In the studied projects, the process of organising was path-dependent in the sense that it did not only build upon professional standards of practice and institutions (i.e. individual professional pasts), but also upon the previous interdisciplinary interactions that took place in the project for achieving mutually adjusted discipline-specific design purposes (i.e. shared past). The accomplishment of meaning and organising through ongoing interdisciplinary interactions depended on having a consistent and coherent understanding of what led to the design issue or situation in hand, and what would it take and mean to adopt a certain course of action as a response to the situation. This had two major components as expressed by the previous research. First, individual experiences from past projects, and professional and institutional standards of practice provided the interaction protocols so that practitioners had the vocabulary, perspectives and concepts to express their opinions in ways that were meaningful to others. These played important roles in guiding the interdisciplinary interactions, and thus, enabled an interdisciplinary environment to which various practitioners could participate without the need for extensive discussions about interactional and communicational protocols. Knowing how to engage with other professionals that they worked with for the first time, on a unique project, was enabled through these guiding principles, which were learned and were part of knowing-in-practice of interdisciplinary design (e.g. the architect and structural engineer knew that they had to have discussions about the external wall thicknesses to fix the slab-edge details and the wall thicknesses in a consistent way). However, each project had unique participants and unique needs which required these guiding principles of interaction to be confirmed, adjusted or swapped with new ones based upon the particular situations that needed to be dealt in practice. This pointed out to the second major resource of organising the interdisciplinary design development: the ongoing interdisciplinary interactions themselves.

The ongoing interdisciplinary interactions provided an additional, complementary resource for practitioners to make sense of what to do next and what ought to be done. The jointly witnessed experience of the past gave a joint appreciation of what led to the present. This included not only witnessing the material changes in the design (e.g. changes in the wall thicknesses), but also, and more importantly, witnessing the past arguments, purposes, judgements, discussions, conflicts and struggles that led to present (e.g. why the wall thicknesses are what they are?). This jointly constructed, and shared appreciation of the present situation (i.e. rooted in the shared past) was indispensable for the members of design teams in perceiving the situations, and engaging with them in certain ways. See Figure 8 in the previous section for a depiction of how these two major resources of meaning-making enabled the practitioners to consistently reason about unique design situations; and thus, enabled them to make sense of what to do and what ought to be done.

Consequently, it can be argued that, what enables meaning and organised activity in interdisciplinary design development is the adjustment of the lines of reasoning of practitioners through interdisciplinary interactions (i.e. the adjustment of the answers to the questions listed in Figure 8 through interdisciplinary interactions). Such an adjustment could be marked as a temporary achievement, and articulated as the achievement of '*a shared sense of purposefulness*' about a design issue. Here, the 'organised activity' corresponds to the orderly, consistent and coherent development of design in parts by different design disciplines based on the *continuously re-established shared sense of purposefulness*.

The explanation provided above extends the previous research cited at the beginning of this section by revealing what it is that is 'becoming' in interdisciplinary design project organisations. It is the basis of reasoning about the situations, or in other words the epistemological orientation of the design team. This 'becoming' happens as a result of the ongoing interdisciplinary interactions around design issues. It is a process of development in which the shared epistemological orientation of design team is constructed step-by-step through ongoing interactions about design issues. This process of becoming (i.e. constructing) enables i) the flexibility required to deal with unique design situations; ii) the temporal continuity and consistency in design development; and iii) the conformity with the professional, institutional and individual standards. It is this jointly driven process of becoming that supports the design team in remembering the past, perceiving the present, and reflecting on the future in commensurable ways; and thus, enabling *continuous re-establishment of a shared sense of purposefulness* to tackle evolving design issues. This jointly developed and shared epistemological orientation, which enables meaning making and organising, is called '*organisational premises'* in this study.

A premise is a supposition or proposition upon which some argument or conclusion rests (Weick 1995). Premises are essential for meaning making and include both factual and value contents that determine meaning making, and therefore courses of actions in situations. A 'premise', as used in this study, is the base of reasoning, and therefore it is what the judgements and decisions are largely based upon. Premises are resources for people who confront situations within which they require making suppositions or assumptions to be able to act further and proceed with what they are doing. Such non-routine situations are abundant in design development as there is always a significant amount of unknowns for practitioners about the future of design, and also about the considerations of the other members of the design team. This does not mean that people act solely upon their assumptions without considering the facts. Rather, this means that, the ways people see, group, interpret, understand, judge, and make sense of the available facts become based on some fundamental value-laden assumptions and suppositions. The concept of *'organisational premises'* captures this base to explain meaning making and organising of practitioners from various disciplines in a consistent, coherent and progressive way.

In this conceptualisation '*organisational premises*' is the jointly developed and used resource for making sense of what to do and what ought to be done. The concept of '*organisational premises*' that is put forward here is a dynamic concept that encompasses individual, professional, and institutional standards of practice; and, more importantly, the ever-developing shared epistemological position of design team towards the past, present and future. In this respect, *organisational premises* are always in flux and develop with every new interaction. When considered with the 'lived directionality' of interdisciplinary design development practices developed in the previous section (i.e. *continuous re-establishment of a shared sense of purposefulness*), the following can be argued: '*Organisational premises*' of a project enable meaning and organising in interdisciplinary design development; and the progressive development of design is due to the ever-developing *organisational premises* which continuously re-configure the discipline-specific expectations, interpretations, and activities in a progressive, coherent and consistent way. A diagrammatic representation of this phenomena is depicted in Figure 9 below.

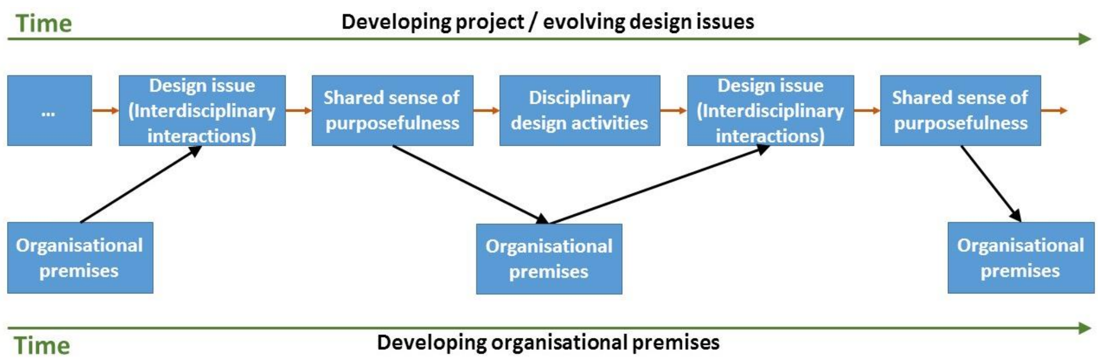

Figure 9 - Organisational premises and design development

This suggests that every interdisciplinary design issue in design development can be viewed as a re-configuration of the views held by the practitioners involved, regarding a certain part/function of the building at a point in time. Every time that an issue is experienced by the members of design team, it is experienced as a re-configuration. Importantly, re-configuration(s) are continuations of previously experienced and handled configurations. Therefore, it is the re-configuration's familiarity that is judged. It is in this sense that evolving design issues are judged and either confirmed, or adjusted, or re-established according to their familiarity. In a design project, practitioners establish a *shared past* of handling configurations, making this *shared past* an essential part of their judgement of the familiarity of new re-configurations. Consequently, it is this continuity that enables practitioners to attribute project-specific significances to various parts and functions of the building, stages of design, and design stakeholders over time; and thus, developing a joint project-specific base that is used for meaning-making in subsequent interactions: the *organisational premises*.

4.6. Observations that Led to the Following Research Questions and Explorations

The initial observations of the EduBuild and OffiBuild projects revealed that interdisciplinary design development largely depended on interdisciplinary transactions through design artefacts. The design artefacts were abundant in all the observed practices. They were talked about, actively used, and specified during the observed face-to-face interactions enabling and guiding the interdisciplinary interactions and organising. Consequently, Chapter 5 explores the active role of design artefacts in enabling the accomplishment of interdisciplinary design development which is established in this chapter.

Another striking point that came out of the initial observations was the limited, or lack of overt use of building information models in design development meetings. Instead, interdisciplinary model-based working and issues around it, were seen as separate and handled largely separately by the practitioners. This led the researcher to explore how interdisciplinary model-based working practices were accomplished; and what the connections between the model-based practices and other interdisciplinary efforts were. These questions are explored in Chapter 7.

CHAPTER 5. THE ACTIVE ROLE OF DESIGN ARTEFACTS IN PRACTICE

5.1. Introduction

The previous chapter argued that interdisciplinary interactions in design development are concerned with maintaining *a shared sense of purposefulness* among the members of the design team. In the practices observed, often such interactions involved or referred to 'design artefacts' - the objects created or used by members of the design team in developing the design (e.g. design drawings, contracts, samples of construction materials etc.). This chapter further explores the argument developed in the previous chapter by establishing the ways design artefacts enter into interdisciplinary design practices and actively contribute. More specifically, the focus here is on exploring the active role that the design artefacts play in *continuously re-establishing a shared sense of purposefulness* among the members of a design team, which is shown to be the 'lived directionality' of the interdisciplinary design development practices (see Chapter 4).

The governing research question for this chapter is Research Question (RQ) 2 – 'What is the role of design artefacts in the practical accomplishment of interdisciplinary design development?'. This chapter adopts an empirical focus on how material and symbolic properties of design artefacts contribute to the accomplishment of making sense of what to do, and what ought to be done in interdisciplinary design development. Inquiring into 'the active role of tools and materials' is highly desired in practice-based research because "*the accomplishment of a practice is, in fact, always attained thanks to both the mastery of skilled, human, embodied actors and the active contribution of a variety of [material and symbolic] tools…*" (Nicolini 2012: 223) (see also Section 3.3.2 in Chapter 3). As introduced in Section 2.3.2.3, design artefacts have active roles in enabling 'intelligibility' in design practices, and therefore the accomplishment of 'organising'. Consequently, from a practice-based point of view, it is not only design artefacts' representational contents that need to be considered in exploring their contribution to the performance of interdisciplinary design work, but also their intermediary and performative aspects (see Section 2.3.2.3). Therefore, a key consideration is explaining how material and symbolic aspects of design artefacts are established, and contribute to making sense of what to do, and what ought to be done in interdisciplinary design development. Figure 10 depicts how this chapter is positioned in, and contributes to the study.

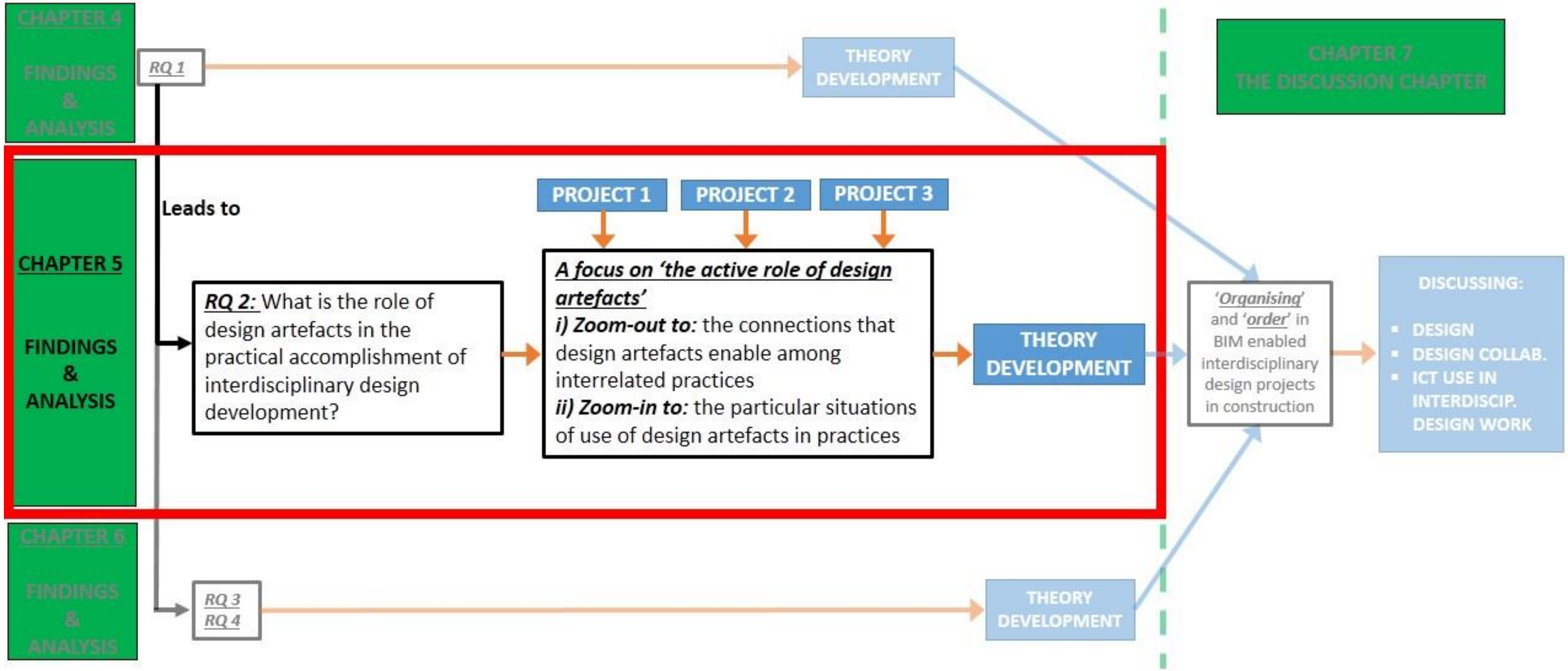

Figure 10 - The position of Chapter 5 in the study, and its contribution to theory development

Figure 11 depicts the structure of this chapter. Design artefacts were abundant in all the observed practices, but they appeared in design development practices mainly in three different ways. Therefore, their material and symbolic aspects were established, and contributed to 'practicing' through these three ways of involvement in practices. Consequently, this chapter investigates the 'active role of design artefacts' through three main sections that correspond to these three ways that the design artefacts appeared in design development practices. Each of the sections involves a series of 'zooming-in' and 'zooming-out' analyses (see Figure 11). While 'zooming-in' to the details of design situations exposes how design artefacts actively contributed to the accomplishment of meanings *in-situ*, 'zooming-out' to the level of interrelated practices associates this with the accomplishment of organisation in interdisciplinary design development. The evidence is presented for the times when i) the design artefact was referred to in order to build up statements and arguments about design issues (Section 5.2.); ii) the design artefact was actively employed during an interdisciplinary design practice (Section 5.3.); and iii) the design artefact itself was the central theme of the discussion (Section 5.4.). The findings are then discussed in the final section of the chapter to develop an explanatory organisational concept that addresses RQ 2.

The concept of 'design information (information)' is employed along with the concept of 'design artefact'. The concept of 'design information' is used to emphasise the contributions of design artefacts in 'informing' the practices (i.e. giving sense to the ongoing practices), and therefore in enabling the progression in the design. In other words, the concept of 'design information' refers to the contribution of 'design artefact' on the 'intelligibility' of a situation (i.e. making sense of what to do, and what ought to be done). For example, while a 'site plan' (i.e. design artefact) has fixed material properties, it can enable a variety of 'design information' through its use in various design practices (e.g. architectural, structural etc.). Consequently, in this conceptualisation, 'design information' is the overall effect of the representational, intermediary and performative aspects of a 'design artefact' (see Section 2.3.2.3), which depend on the material, symbolic and situational particularities. This coupling between 'design artefact' and 'design information' emphasises the contributions of design artefacts to meaning-making, and enables a distinction between 'data' and 'information' to be drawn. In this distinction, the concept of 'data' is relevant to the internal operations of technology, and the concept of 'information' is relevant to people who perform design development. Connections and implications of these concepts on each other will be further explored in the following chapters.

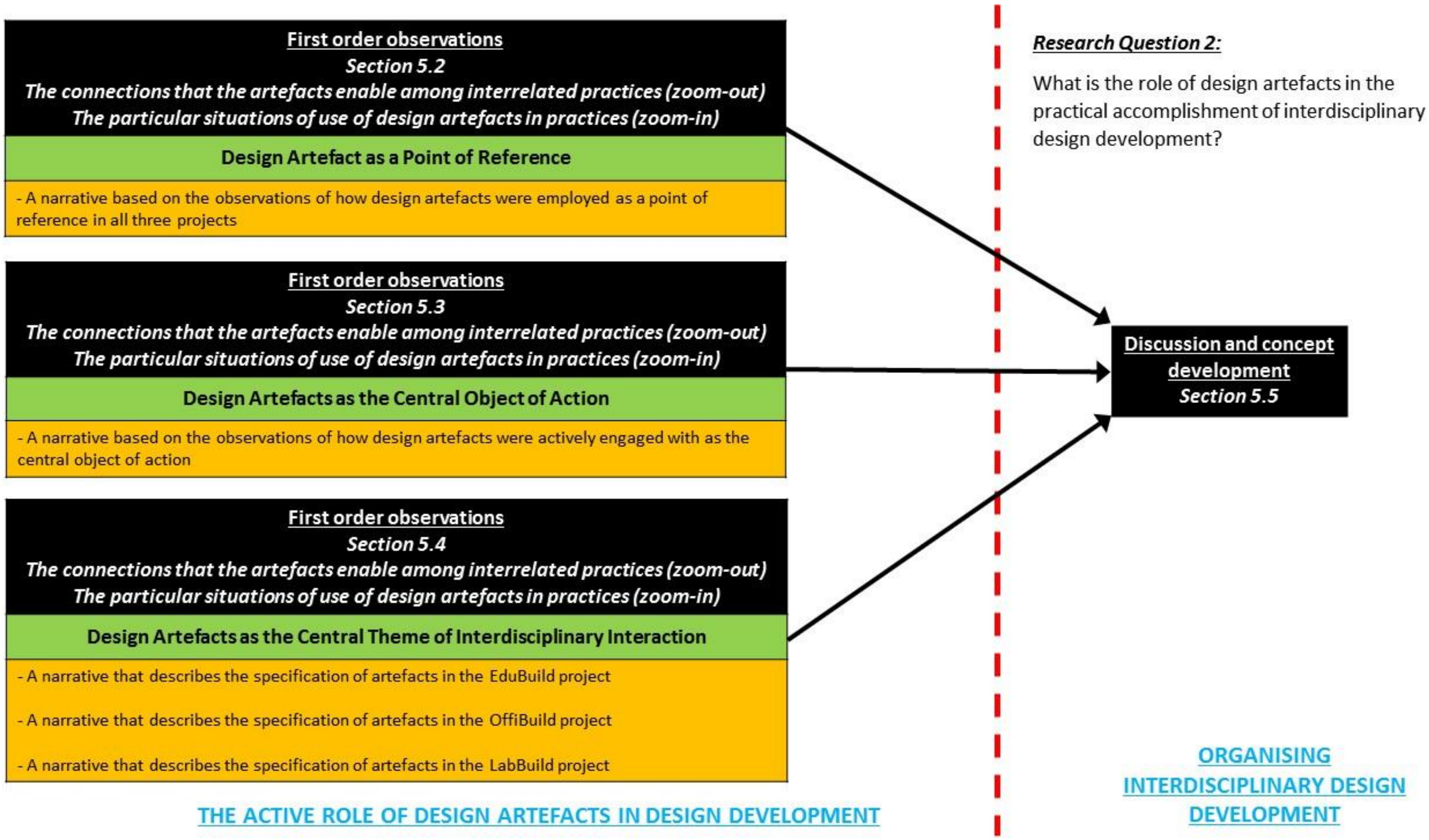

Figure 11 - Data, analysis, and theory development structure of Chapter 5

5.2. Design Artefact as a Point of Reference (zoom-in & zoom-out)

References to various design artefacts were abundant in the discussions that were held during the observed design-related practices. The practitioners very often used references to the artefacts in order to build up their arguments, and make statements during the discussions about design issues. For instance, in Event EE 1, when the representative of the M&E sub-contractor tried to understand the rationale behind using wooden ceilings in the board room, he wondered how the ceiling was specified in the 'client brief'. Also, in Event EE 3, the M&E sub-contractor referred to the 'updated occupancy rates' and 'results of the updated ventilation calculations' in order to argue that some of the doors needed to be equipped with air transfer grills. Some of the references made to particular design artefacts in the observed practices are listed in the Table 5 below.

Instance	Topic	Practitioner	Referred design artefact(s)	Statement / argument made
No1: EduBuild Project – Event 4 (EE 4)	Servicing the Video Pod in the atrium	M&E sub-contractor	Service strategy document	To argue that service requirements of the video pod were neglected
No 2: EduBuild Project – Event 3 (EE 3)	Need for extra air transfer grills on the doors	M&E sub-contractor	Occupancy rate calculations and updated ventilation calculations	To argue that some of the doors need to be perforated in order to be equipped with air transfer grills
No 3: OffiBuild Project – Event 2 (OE 2)	Preparation of design documents for planning submission	Design manager of the main contractor and M&E consultant	External lighting strategy document	To specify a design task (i.e. developing the external lighting design at strategical level as a necessity of planning submission)
No 4: OffiBuild Project – Event 2 (OE 2)	Preparation of design documents for planning submission	Architect	Landscape survey results	To argue that the existing landscape surveys would not be useful for the M&E consultant in developing the external lighting strategy

No 5: OffiBuild Project	Evaluation of alternative window systems	All	Manufacturer specification documents; a variety of illustrative, numerical and textual content	To explore the implication of various options from different discipline-specific perspectives (e.g. ventilation, internal space usage etc.)
No 6: OffiBuild Project	Scheduling design targets for various disciplines	All	Construction Proposals	To specify a level of design development
No 7: LabBuild Project	Developing the signage design	Architect and the representative from the client's organisation's team	Floor plans and facilities coding standards of the client organisation	To plan future coordination for signage design development

Table 5 - Examples of references made to design artefacts in design development meetings

References to design artefacts were used in the case studies for a variety of purposes during design discussions. In the cases where references were made to design artefacts, the artefact was referred to as a material marker which had a particular significance (i.e. symbolic meaning) for the parties of the discussion in the specific context of the situation. It was this particular significance which informed the situation, and therefore enacted *design information* through the design artefact. The design artefact was a material marker in the sense that its capability of fixing and representing a set of aspects of the design in a particular and interrelated way was exploited for creating expressions and enabling impressions in discussions. In other words, all design artefacts represented materially fixed re-configurations of various discipline-specific views, design stages, and the parts/functions of the building design; and it was this feature that was employed in discussions in a number of ways to create expressions and enabling impressions to inform the situations and practitioners.

In the previous chapter, it was argued that the efforts of practitioners in the observed meetings were oriented towards *noticing lacks of clarity*, *recollecting shared and professional pasts*, and *co-projecting future actions*. Here, it can be seen how design artefacts were referenced to support these efforts, and thus informed situations. It can be deduced from Table 5 that references to design artefacts helped i) *recollecting the past* (i.e. professional and shared) in order to inform the actual design situation (e.g. Instance No 5);

ii) supporting *noticed lack of clarity* by assigning authority (e.g. Instance No 2); iii) grounding the *co-projection of future actions* (e.g. Instances No 6 and 7).

It was observed that the same artefact could be referred to enact a variety of *information* according to material, symbolic and situational particularities. For example, Instance No 6 in Table 5 depicts a design situation in the OffiBuild project, in which Construction Proposals (CPs) were referred to specify a particular level of design development. Although CPs are essentially contractual documents that describe the details of the work that would be contracted to the design team, in this case the design manager of the main contractor referred to CPs to set design targets for the members of the design team. In other words, the design manager of the main contractor produced a symbolic meaning about his expected level of design development with the reference he made to a design artefact (CPs) which is normally understood as a contractual specification. This was meaningful and had an *information* value for the members of the design team because they all had a professional understanding of what developing the design to the CPs level might mean.

In the EduBuild project, references made to CPs were sometimes used in other ways due to the significantly bigger shared past established about them. The understanding of the practitioners about CPs in the Offibuild project were based on their previous professional experiences, whereas in the EduBuild project, CPs had already been established and attached to the contracts of the design consultants at the time of observation. Therefore, the design team in the EduBuild project had a shared past concerning the CPs that enabled the production of project-specific symbolic meanings for them. Consequently, in the DCMs of the EduBuild project, CPs were generally referred to when there were disagreements about the scope or requirements of the design among various members of the design team. In other words, the EduBuild CPs were mostly used to recollect the past and give authority to arguments, which was very different from references to CPs that were used in the observed DCMs of the OffiBuild project.

In this respect, in a similar way to Wenger (1998), it was observed that references to design artefacts were used to create points of focus around which meanings were organised and *information* was represented during discussions. Design artefacts are objects that are generally named after their materiality, or in other words their representational aspects, such as engineering calculations that represent the inner working of engineering systems, plans that represent building geometry, and construction proposals that represent contractual obligations. However, when they are referred to in discussions in interdisciplinary interactions, perhaps more significant are the intermediary and performative roles of these artefacts. The symbolic meanings of artefacts depend on the professional and shared pasts of participants as well as to the particularities of the design situation. Even when the artefact is not materially present but only referred to, the symbolic meaning of it enables expressions and developing impressions among members of the design team to be articulated. This corresponds to the intermediary role of design artefacts. As in the example of the references made to CPs, reference to the same contractual document can be used to set design tasks in terms of level of development of design, or to provide authority for an argument in a situation of conflict. In both cases, parties are aware of the implications of the reference made to the artefact within the particularities of the given situation, and hence, the contribution of the artefact to the intelligibility of the situation.

Moreover, each reference made to a certain artefact foregrounds one, or a limited set of particular aspects or considerations, thus providing an orientation to the situation towards certain directions. This is the 'performativity' of making references to design artefacts in interdisciplinary practices. The same wall can appear in a myriad of artefacts such as plans, Gantt Charts, detailed drawings and 3D models. However, the same wall gains its meaning within the whole of the artefact it belongs to, and the situation into which the artefact enters. It is the particularities of the situation and the symbolic meaning of the artefact that direct people's attention to certain aspects of the wall, thus, being performative. For example, Instance No: 5 presented in Table 5 above refers to a situation where manufacturer specifications were referenced to evaluate different window alternatives. In a situation where different window alternatives are discussed, such references represent the specific limitations of each alternative that cannot be changed, thus framing the scope of discussion and giving it a conclusive orientation.

This concept can be extended to establish a more general account of how the practitioners knew about various potential significances of a design artefact so that they were able to make consistent sense of the reference made to it in a particular discussion/situation. Practitioners needed to know the 'assumptions' embedded in the design artefact in order to appreciate the potential significances of it, and to make sense of the reference to that design artefact in a particular situation. The design artefact was always an abstract representation of a fragment of reality and therefore there were always assumptions embedded in the making and use of it. As the evidence above suggests, the assumptions were sometimes guessed through professional past experience of working with same kind of artefacts, and at other times practitioners relied on their shared past experience in knowing the assumptions embedded in the making and use of the design artefacts in the project. The same desire of knowing assumptions appeared as explicit questions when references were made to a discipline-specific design artefact about which the other members of the design team did not know much about the embedded assumptions. For example, in one of the DCMs in the Offibuild project, the representative of the M&E consultant claimed that the ventilation strategy for the auditorium had to be amended as the previous strategy did not meet the ventilation requirements. He claimed that one of the options was mechanical ventilation which had disadvantages in terms of acoustics of the auditorium (i.e. due to the noise of running mechanical parts). The other option was to have windows with parts that could be opened for natural ventilation of the auditorium (i.e. passive ventilation). The passive ventilation option was not found completely satisfactory considering the noise of the street that could disturb events in the auditorium. At this point in the discussion, other members of the design team started to ask questions about the assumptions embedded in the ventilation calculations in order to make further sense regarding what 'satisfaction of ventilation requirements' meant. They asked for example:

- What was the occupancy rate of the auditorium taken into consideration in the calculations?
- What was the amount of time that could be spent before the people in the auditorium would feel need of ventilation through opening the windows?
- How frequent the windows would need to be opened and for how long?
- Whether the combined use of mechanical ventilation and passive ventilation were considered before interpreting the results of the ventilation calculations as pointing to two possible distinct solutions?

These questions aimed to reveal the assumptions embedded in the design artefact (i.e. ventilation calculation results) in order to attach a meaning to it in the given situation. Practitioners knew that the future complex real situations were configured and abstracted in particular ways for the ventilation calculations, and the people from other disciplines needed to access to these assumptions to process *design information* through the references made to the design artefact. Therefore, the *design information* could be used to the extent that the assumptions (i.e. particular perspectives and abstractions) embedded in the design artefact were known to the parties of the discussion.

5.3. Design Artefact as the Central Object of Action (zoom-in & zoom-out)

Design artefacts were also used as the central object of activity in the observed practices in which their material (i.e. representational) aspects were visible to practitioners. This happened rarely during the DCMs of the EduBuild project and during some of the meetings observed in the LabBuild project. However, design artefacts were frequently used as the central object of action during the other meetings observed in the LabBuild project, the coordination workshops in the EduBuild project, and the DCMs of the OffiBuild project. Some of these instances will be described below to present an account of how design artefacts gave sense to practicing.

Similarities were observed between the instances when design artefacts were referred to and the instances when they were used as the central object of activity. First, the need of practitioners to know the assumptions embedded in the making and use of the design artefacts was present even when design artefacts were actively used as the central object of activity. For example, at the first observed design meeting of the LabBuild project, practitioners used a number of M&E and architectural drawings in order to discuss the coordination requirements between the architectural, M&E and clean room systems. The LabBuild project was a fast-tracked project in which design and some building activities ran concurrently. In this respect, participants of the meeting often mentioned the actual situation on the site while actively using the design artefacts in order to reveal the consistency of the assumptions embedded in the artefact and the actual conditions of the construction on the site.

Another set of instances about questioning assumptions embedded in the actively used design artefacts took place at the early stages of the observation of the OffiBuild project. At that stage each DCM involved a variety of discussions about interrelated building systems (e.g. such as building openings – an architectural system; ventilation strategy – an M&E system; and beam spans – a structural system). At the end of these DCMs, designers were clear about the alternatives they needed to investigate and present in the following meeting. Nevertheless, in the following meeting, always a considerable amount of time was spent on discussing how the alternatives from the previous week were being developed, what kind of issues were considered while developing the alternatives, and therefore what kind of assumptions were embedded in the related design artefacts brought to the meeting. These instances required members of the design team to provide the background thinking to their decisions while actively engaging with the design documents brought to the meeting. It was observed that other members of the design team joined the conversation with their further questions or comments only after the explanations about the reasoning that was followed for developing design alternatives and corresponding artefacts.

On the other hand, the use of design artefacts as central object of activity involved enacting various pieces of *design information* according to the team member's knowledge of their specialism and concerns (see for example Event OE 1 in Chapter 4). Indeed, this was the whole point of coming together and discussing design issues through active engagement with design artefacts. Nevertheless, although different members of the design team enacted different *information* on the same design artefact, they were also concerned about basing the meaning they attached to the artefact on correct (e.g. reflecting the latest situation on the construction site) and consistent assumptions (i.e. sharing the considered assumptions with others during the meetings) as explained above.

Further, enactment of *design information* through the use of design artefacts as central objects of activity was also situation-specific, which was similar to the use of references to design artefacts. This implied that a single design artefact could play a part in many different design discussions and practitioners could use it to inform a large variety of design discussions. In other words, a single design artefact could reveal a large variety of *design information* according to the situation it was used in. The site plan in the OffiBuild project was a typical example of this. Prior to the submission of the planning application, the site plan of the project had been the central object of action for a variety of design discussions in a number of DCMs. Some of the topics of these discussions can be listed as:

- Site access for machinery and material deliveries during construction;
- Access to building (as part of the design of the entrances and exits of the building);
- Potential future developments around the site of the project;
- Orientation of the building and ventilation strategy;
- Landscaping design;
- Discussions about bridging links between the existing building of the client organisation and the new one;
- Piling plan;
- Building façade design (i.e. what kind of material would be used at different sides of the building);

- Site installations of the temporary facilities (i.e. facilities for the project team);
- Location of the bicycle parking area (which was required to gain BREEAM credits);
- Location of the car parking areas;
- Rubbish storage areas.

In each of these design situations participants of the meeting interacted with the site plan. They pointed to parts of it, sketched on it, used coloured pens to delineate some parts of it and so on, while discussing various design issues. In this respect, the significance and use of the site plan varied according to the particularities of the situation. Therefore, the site plan was used in supporting the creation of points of foci for which meanings were organised similar to referring to a design artefact in a statement.

Nevertheless, there were also differences between using the design artefact as the central object of activity and as a reference in order to enact *information*. When the design artefact was referred to, it was generally used as part of making an argument or statement. On the other hand, when the design artefact was the central object of activity, a tendency to inquire was observed. For example, in the DCMs of the EduBuild project, it was very rare that the practitioners actively used the design documents they brought to the meeting. When they used them, it was either because one of the practitioners explicitly invited the others to pay attention to the artefact to be able express himself/herself, or when practitioners could not make sense of each other's references to a particular design artefact. Furthermore, when design artefacts were actively used, no matter whether the aim was to explore opportunities or make statements, it was observed that the conversation jumped between various topics: the artefact had a triggering power. It was observed that this aspect was appreciated by the practitioners as they brought design artefacts to interdisciplinary meetings when they wanted to have an exploratory discussion. In conclusion, actively working with design artefacts was different from referring to design artefacts in at least two ways. First, the design artefact triggered new questions, topics and discussions when it was the central object of activity. Second, this mode of working with design artefacts was preferred by the practitioners when verbal references were thought to be insufficient.

One example of this took place towards the end of the observation period in the EduBuild project. In this instance, the representative of the M&E sub-contractor invited the other participants of the meeting to consider a drawing that showed the M&E installations on the roof in order to explain that the number of access bridges stated in the CPs were less than what was needed. Following this, he started to explore the installations on the roof with the representatives of the architect and M&E consultant by mainly actively using the drawing. Although, the main aim of the representative of the M&E sub-contractor was to find a solution to keep the number of the required access bridges at the number stated in the CPs, at the end of the exploration, none of the explored potential changes to the roof installations were satisfactory for all the participants of the project. As a result, the representative of the M&E consultant stated that this was one of the things that would not be agreed by the client because it was a health and safety issue (i.e. access bridges were instrumental for fire escapes and maintenance), and therefore whatever number was needed had to be installed. Following this statement, the representative of the M&E sub-contractor took a note on the drawing saying that "*the required number of access shall be provided*".

Another unique aspect of actively working with design artefacts that was observed was the exploitation of their power of materialisation of the notional work of design. For example, when resolution of an interdisciplinary design issue depended on working with the geometric relationships among various elements of the building, a design artefact was used as the central object of activity. The design artefact was capable of representing the material relationships among various elements of the building to the desired geometrical precision and therefore allowed the practitioners to work at the required precision of the material relationships. In Event OE 1, it was shown that the members of the design team had an extended discussion around system level design and features of the curtain wall system such as transportation of its elements, the number of openings and so on. This was a system-level discussion that did not require the consideration of geometric measurements of the parts of the building but only of some system-level interrelations among various parts and functions of the building. This discussion utilised the elevation drawings of the building that did not include any dimensions on them. Months after that conversation, in another DCM, members of the design team worked with the curtain wall system at a much higher geometrical precision level (at millimetres level) when they discussed the slab edge details of the ground floor. Moreover, during the discussion about the fixation details of the curtain wall at the slab edges, the dimensions were measured on the slab edge detail drawings to assist the practitioners in their discussions. Consequently, both discussions involved exploration of various aspects of the curtain wall system through design artefacts but the *information* needs of the practitioners changed the preferences of the practitioners in terms of the content of the artefact and the mode of working with that. In this regard, the required content and level of detail in a particular situation was connected to the *information* needs in that particular situation.

Design artefacts were also used in combination to assist the practitioners in considering various interfaces materialised at different fashions (i.e. using photos, sketches and scaled geometrical drawings in combination; using different drawings that had different levels of details simultaneously; using old and new drawings simultaneously to expose and trace the changes made in a variety of parts and buildings of the system and so on.).

The materiality related to design artefacts was not only about the material representation of various levels of details or various aspects of future material relationships among the parts/functions of the building (i.e. various contents) through design artefacts. There was also a second dimension of the materiality stemming from the material properties of the kind of media involved in the creation and/or use of the design artefact (e.g. paper, e-mail, AutoCAD files etc.). There was a variety of design media available to practitioners that enabled creation, transfer and use of design artefacts according to the convenience (i.e. *information* needs) of practitioners. For example, there were paper documents of various different sizes (e.g. A4, A3, A1, A0 etc.) and digital documents with varying functionalities and integration capabilities such as standalone e-mails and editable .dwg files and so on. As different media presented different material properties to work with, practitioners exploited their varying strengths according to their *information* needs in particular situations. For example, during the first observed coordination workshop of the EduBuild project, the floor plans were printed at A0 size which enabled everyone around the table to see and physically interact (i.e. pointing, sketching on etc.) with the floor plans at the same time. A0 size paper drawings enabled the participants of the coordination workshop making measurements on the drawings using rulers. Furthermore, A0 sized paper drawings provided plenty of space for taking notes on the drawings or marking particular spots as reminders for future. During the same meeting, practitioners also used the projector in the meeting room to open files for drawings with different levels of detail from the computer when the A0 drawings were not enough to satisfy the *information* requirements for a particular topic of discussion (e.g. when a higher level of detail or a different type of content that was not present in the floor plans was needed). Therefore, practitioners skilfully used various material aspects of different media in combination in order to meet their information requirements in specific situations. In the example given here, the strengths of the large-sized paper floor plans were combined with the different strengths of the digital drawings that could be changed and viewed easily and quickly according to the changing needs of the practitioners during various discussions.

5.4. Design Artefact as the Central Theme of Interdisciplinary Interaction (zoom-in & zoom-out)

The two previous sections provided explanations regarding how practitioners made sense of existing design artefacts during the observed interdisciplinary practices. However, in the observed practices, there were also instances when the *production*, *handling* and/or *use* of design artefacts were the central theme of interdisciplinary discussions. In this section, examples of these instances will be described in order to complement the explanations provided above.

Design artefacts were numerous and densely employed in design development practices in the observed projects. The previous two sections revealed that enactment of meaning/information through a design artefact depended on a number of material, symbolic and situational factors. It has been shown that i) a shared understanding of the situation; ii) a shared understanding of the assumptions embedded in artefacts; iii) appropriate materialisation of the interrelations among various parts/ functions of the building in the artefact; and iv) appropriate material properties of the media of the artefact were all influential in enabling meaning, and therefore for purposeful interdisciplinary communication through and around design artefacts. This section will describe instances of how these material and social conventions were discussed and established in the practice through the discussions about the *production*, *validation*, and *use* of design artefacts. This section will be structured around three sub-sections (Sections 5.4.1, 5.4.2, and 5.4.3) that describe instances from the three observed projects.

5.4.1. The EduBuild project

In the EduBuild project, planning and tracking of the development of design were articulated in terms of needs for *production, validation* and/or *use* of design artefacts by various design disciplines. Therefore, the statements made about *production*, *validation*, and *use* of design artefacts were seen as indicators of developmental steps of different parts of design developed by different design disciplines. Nevertheless, there were two different kinds of design development tasks that attracted interdisciplinary attention in the EduBuild project as observed in the DCMs. As mentioned in the previous chapter, the agendas of DCMs in the EduBuild project were based on two sections. While the ‘previous minutes’ section was to establish and solve the unexpected design issues, ‘updates’ section of DCMs was to inform the design team about expected and ongoing design development activities of each discipline. Planning and tracking of expected and eventual developments in discipline-specific areas of the design (e.g. architectural design) were the topic of the 'updates' section and these topics were articulated in terms of the needs for *production*, *validation* and *issue* of various design artefacts. On the other hand, 'previous minutes' section had a more problem-solving focus for the unexpected issues. Nevertheless, planning and tracking of solutions to design issues that were discussed during the 'previous minutes' section was also articulated through the needs for *production*, *validation* and *issue* of design artefacts. However, the different characteristics of these two sections caused differences in lengths and courses of the design artefact-focused discussions.

In each DCM, first, there were ongoing, familiar and expected requests and announcements from each discipline regarding *production*, *validation* and/or *use* of design artefacts that took place during the 'updates' section of the DCMs. These requests and announcements were indicators of the level of design development in specific disciplines (e.g. architectural design), which was why representatives of various disciplines expressed updates through statements focused on the needs for *production*, *validation* and/or *issue* of design artefacts. These discussions during the 'updates' section of DCMs reflected the expected and eventual development steps of design for various design disciplines according to the previously established design principles, strategies and documentation procedures. These involved, for example, representatives of the M&E sub-contractor requesting various sets of drawings from the representative of the architect in order to further detail the M&E design. Another example was the representative of the architect requesting a set of documents from the M&E sub-contractor in order to review, comment on or mark-up. These discussions involved i) a brief description of the design artefact (e.g. ground floor reception area lighting drawings); ii) why it was needed at that particular time of the design (i.e. what the significance of that particular set of drawings was in progressing with design and how they would be used); iii) the status of the design artefact (i.e. which version of the drawings were expected, what kind of validation or reviewing processes it had been or would be through?); and iv) how the transfer of the design artefact would happen (e.g. whether it would be e-mailed or uploaded to a folder in the document management system etc.). However, it was very rare that all these four aspects were mentioned for the expected and familiar activities around design artefacts that were noted in the 'Updates' section of the DCM agenda. This was because different disciplines were aware about the level of design development of other disciplines and had an understanding about others' needs. Also, there were established procedures in place for validation, version checking and sharing of design artefacts. Therefore, when the points listed above were mentioned in the DCMs for the expected and familiar requests about design artefacts, these were more about re-confirming or re-clarifying the shared understandings around the above listed points among the parties and therefore were passed very quickly. These re-confirmations rarely led to further discussions when the mentioned points were perceived as unfamiliar or unexpected by one or more of the parties. In these rare cases, further conversations took place between the parties to come to a shared understanding around the points listed above. These discussions about the *production, validation,* and *use* of design artefacts directed the practitioners in prioritising their tasks while providing clues about how the requested information would be used at that stage of the design.

Second, there were discussions around the *production, validation* and *uses* of design artefacts about the unexpected/unfamiliar design issues. In the previous chapter, it was stated that the 'Previous Minutes' section of the DCMs in the EduBuild project was mostly about discussing this kind of issues. Typically, at the beginning of these discussions, legitimacy of the source (i.e. assumptions embedded in the design artefact) that exposed the issue were confirmed discursively before the further exploration of the issue. For example, when one of the participants said that there was a more-recent development/artefact related to that specific issue, further discussion of the issue would then be based on the most-recent development/artefact. Most of the time, these discussions ended with the *co-projection* of what needed to be done next in terms of *production*, *validation* and *use* of design artefacts. Similar to the situations where regular procedures and transactions around design artefacts were re-confirmed and re-articulated, action strategies to coordinate the unfamiliar and unexpected design issues also typically specified design artefacts in terms of the four points stated above.

In these cases, the validation process(es) of the design artefact(s) that was/were planned to be created (or modified) were always explicitly discussed and articulated to make sure that all the implications of the discovered issue were acknowledged and managed in related discipline-specific parts of the design. Therefore, these discussions included determinations of who was supposed to produce, comment on, e-mail, review, mark-up and so on, and in which order. For example, revised occupancy rates and overheating calculations were two separate design issues that appeared in the 'previous minutes' section of DCMs. However, they needed to be considered together when formulating the validation process as they both had implications on the ventilation strategy and the thermal model. Furthermore, the development of FF&E equipment schedules was also related to the confirmation of the revised occupancy rates and therefore they needed to be considered together when the validation process was developed. In this respect, part of this joint consideration required to identify the actors that needed to validate them and the type and order of the validation.

How the artefacts would be used was also explicitly discussed in such cases. The discussion about a design issue would establish the *lacks of clarity* and the corresponding *information* needs. Practitioners would then specify the design artefact and the validation process for the artefact needed to satisfy the established *information* requirements. Nevertheless, during the specification of the design artefact, how it would be or should be used was always re-articulated among the parties of the discussion for re-confirmation of the intended use of it for the resolution of the design issue. The agenda point below is from the 'previous minutes' section of one of the DCMs in the EduBuild project and reveals how resolution of design issues were planned and tracked around *production*, *validation* and *use* of design artefacts.

> "*Roof duct & pipework layouts issued and uploaded into model. M&E sub-contractor issued insulation thicknesses for architect to finalise step-overs."*

In this example while an 'issued layout' and list of 'insulation thicknesses' described the *production* of self-contained, ready-to-use design artefacts, the 'upload' in the model implied that the design of the duct & pipework presented in the layouts were coordinated (i.e. *validated*) with other parts of the M&E systems on the roof. Consequently, articulation of the procedures of 'issuing' and 'uploading' had significances that were important for those who would work with these artefacts. 'Issuing' and 'uploading' were procedures where the *information* passed from one source of information (e.g. the M&E engineer) to another source of information (i.e. the issued drawings folder in the document management system; the information model) signalling a *validation* from M&E sub-contractor. On the other hand, the form of the 'layout' as a drawing implied that it was suitable for *using* in geometric coordination. Combination of the form of layout with the list of insulation thicknesses implied that *using* these two artefacts in combination enabled the precise design of the step-overs on the roof. However, in the statement, it was explicitly stated that the insulation thicknesses were issued for the design of step-overs. This implied that, for example, the thicknesses *could not be used* for estimating the material cost of the insulation. Therefore, the design artefact planned for the coordination of an unexpected design issue was skilfully specified in terms *production*, *validation,* and *use* in order to satisfy the information needed to coordinate the resolution of the issue (i.e. finalising the architectural design on the rooftop according to the latest amendments in the M&E installations on the rooftop).

5.4.2. The OffiBuild project

In the OffiBuild project, planning and tracking of the development of design were also formulated through the statements for the *production, validation* and/or *use* of design artefacts by various design disciplines. Nevertheless, in the OffiBuild project, there were different kinds of considerations regarding the *production*, *validation,* and *use* of design artefacts in comparison to the EduBuild project. These differences were revealed as differences in the scopes of the discussions that were focused on design artefacts during the DCMs of the OffiBuild project.

In the previous chapter, it was stated that developing design in the OffiBuild project played out as shifts in focus of attention of the members of the design team from building-systems level to system-components level over the period of observation. A corresponding shift was also observed in terms of the scope of the interdisciplinary discussions that were focused on planning and tracking the design development through the statements about *production, validation*, and *use* of design artefacts. At the early stages of the observation period, documentation requirements of the planning application submission drove the interdisciplinary design development effort. Producing the documents for the planning application submission required the designs – according to each discipline – to be planned according to the intermediate design artefacts that needed to be produced in order to develop the design step-by-step to the level required by the planning application submission. Typically, at the end of each DCM, the design manager of the main contractor asked all the representatives of design consultants i) what design artefacts they had recently been working on; ii) what design artefacts they would issue next and when; and iii) whether their design development relied on the artefacts that would be produced by another member of the design team. Along with the answers to these discussions, planning and tracking of design development was achieved in order to head towards the submission of the planning application.

During these early stages of the observation period, the design artefacts produced by various members of the design team did not need to be coordinated tightly with each other, since the focus of design development was mainly at building-system level rather than component level. Mainly non-detailed architectural documents - such as floor plans, the site plan, and initial room data sheets - were shared with other design consultants which allowed them to develop design strategies and discuss them during DCMs. The updates to these shared documents were made in a linear fashion: typically, the architect passed architectural design to practitioners in other disciplines and waited for the comments. After comments were received, the architect updated documents and passed them again to others for further design development. This kind of approach to artefact production and transfer required very few discussions regarding validation and transfer procedures of design artefacts compared to the later stages when more-detailed design needed to be established in every discipline. As exemplified in Event OE 2 (see previous chapter), at that time of the design project, members of the design team did not need to coordinate the design artefacts much while preparing for the submission of the planning application. However, with the developing design and shifting focus from planning application submission to completing the documentation requirements of the RIBA Stage D and proceeding with the documentation requirements of the Stage E, discussions about *production, validation* and *use* of design artefacts were increasingly needed. As the design moved towards detailed documentation, issues regarding the versions, contents, validation processes (i.e. commenting, marking-up etc.) started to be more important for the members of the design team.

At the beginning of the RIBA Stage E, previous exploration of building systems and identification of potentially problematic/irregular areas of the building that had to be coordinated had already been discussed to some extent, and these played an important role for defining the *information* requirements, and therefore defining artefacts expected for the RIBA Stage E. For example, the roof was one of the systems where irregularities that needed to be carefully coordinated was expected. Therefore, in one of the DCMs at the beginning of the RIBA Stage E, what artefacts needed to be developed was discussed in detail in order to decide what sections and layouts were needed to be produced for adequate coordination of the roof design. By contrast, such detailed discussions were not held about what design artefacts would be needed for the RIBA Stage E design of the more conventional building systems (e.g. staircase sections of fire exits and updated floor plans). Production of these design artefacts were taken for granted and they were just listed in the required documents list for the RIBA Stage E.

Once the lists of deliverables for the RIBA Stages D and E were finalised and announced by the design manager of the main contractor, a more scrutiny of already-produced design and accompanying artefacts took place. This change of focus was the start of many artefact-focused discussions in the Offibuild project. For example, at the beginning of the RIBA Stage E, in one of the DCMs it was discovered that the current drainage plan used an old version of the ground floor plan. This triggered the discussions about how interdisciplinary checks of different design artefacts and version control would be handled. During that discussion, it was decided that all structural and architectural designs would be included in *one* information model under the ultimate control of the architect, and the design in that model would be assumed to be the central source for the latest set of circumstances in the design project. However, later on in the project, this decision was re-visited because the model had been changing continuously and other disciplines had been working with the static drawings issued from earlier versions of the model. This situation required the design team to hold numerous follow-up discussions about how they would keep the previously issued drawings up-to-date according to the latest changes in the model. This was an ongoing concern for assuring that all the disciplines in the project worked with the latest version of the design, and that the previously signed-off artefacts were updated according to the changing model.

In addition to the information model, Room Data Sheets (RDS) were also aimed to be used to organise the various connections among various disciplines, and therefore RDS also needed constant interdisciplinary updates. In this regard, the RDS, which were supposed to be produced and continuously updated by the main contractor, architect, client (i.e. because the client wished to procure and install some of the equipment) and M&E engineering consultant were also a topic of ongoing discussions. The developing design not only led RDS to be continuously updated but also RDS was seen as a central artefact to track the design and procurement of Furniture, Finishings and Equipment (FF&E) of the OffiBuild project. All the different contributors and their interdependent character related to the development of RDS also made the design team to question who 'owns' RDS, and made RDS one of the central topic of discussions.

Documenting the detail of the design progressed as the discussions regarding the *production, validation,* and *use* of different artefacts started to appear as concerns that needed to be coordinated due to the increasing number of design artefacts that were interlinked. The discussions around establishing a Request for Information (RFI) system among the design team was an example of this. This is presented as an event (OE 3) below.

Project OffiBuild – Event 3 (OE 3) – RFI system and coordination of information needs

> *The client Project Manager (PM) of the OffiBuild project attended most of the DCMs, however frequently stated his concerns about not having access to the design, except from what he had been seeing in DCMs. Therefore, on a number of occasions he asked the design team to create a mechanism for smooth interaction between him and the rest of the design team. In one of the DCMs it was agreed to create a*

Request for Information (RFI) folder in the online document management system with the main recipient the client PM. During the course of these discussions other members of the design team stated that they could use the same folder for communication among the design team or create a separate similar folder for tracking the changes about particular design issues. However, the design manager of the main contractor rejected this, saying that the information transactions among the design team should be quick, and such a system would slow down the process. He argued that, according to his experience, such formal and exposed systems could be used for 'different agendas' such as an evidence base in cases when problems arise within the design team and problems start get contractual. He stated that he did not like working like that. The design team members stated that they did not intend to use it as an evidence base for potential future conflicts, but only wanted to have an information exchange system in place for efficient coordination of certain issues. However, the design manager from main contractor did not change his opinion on this issue. Following this final decision, the architect asked the other members of the design team to at least describe what the e-mails that were sent to them were about in the "subject" field of the e-mails instead of only providing generic subjects such as "for your information" or "the name of the architect company".

Another similar event exposed how the assumptions about the design artefacts had to be adjusted through the procedures and discussions regarding their *production, validation* and *use*. In the event (OE 4) presented below, even the assumptions about a very 'evident' aspect of the design needed to be discussed in order to be successfully communicated through the use of an artefact. Although the penetrations to concrete slabs were a common application in all reinforced concrete buildings, how this would be documented in the design was discussed in one of the DCMs as presented below.

Project OffiBuild – Event 4 (OE 4) – Penetrations to concrete slabs

In one of the DCMs towards the end of the observation period, the representative of the M&E consultant made the point that they had already discussed that in one of the riser areas on the first floor the slab had to be partly extended. The reason for this was because some racks were planned to be installed in that area. The representative of the M&E consultant added that although this was discussed and then e-mailed, in the information model the slab was still not extended. Then a *discussion started regarding how the changes were recorded in the design project. How were they followed up after being marked-up on the online documentation system? During this discussion about procedures about the design artefacts, the representative of the architect asked about how the integration between documents from different disciplines (e.g. such as drawings referring to each other and/or integration of drawings and specifications) would be handled. He gave the specific example of penetrations to concrete slabs which represented an aspect of the design that could appear in various discipline-specific design artefacts. Then a discussion about how the penetration to concrete slabs would be shown began: In which document they should have been shown? Architectural drawings or structural drawings or specifications? Was it only a matter of covering self contractually or was it a significant piece of information for the design team and the construction team? It was argued that everyone knew there had to be some penetrations and it was evident, but then another member of the design team asked whether it was really evident. Another member of the design team asked: what makes 'evident', evident? Who would be responsible if penetrations were forgotten? All these questions were reviewed over the course of the discussion that started with the lacking extended slab in the riser area.*

The updates and negotiations about the procedures for *production, validation,* and *use* of design artefacts increasingly took place in the DCMs over the observation period. Occasional discoveries of inconsistencies among design documents (i.e. such as a drainage plan using an old version of ground floor plan) made these discussions more important in the eyes of the design team, and led them to be doubtful about the *production*, *validation*, and *use* of numerous artefacts in the project. For example, a commonly asked question during the DCMs was how many of the discussed issues about an area of the design were currently in the model or in the online document management system?; and what were the steps to be taken for further developing design artefacts about those areas of design? As part of the concerns about the consistency of various design artefacts, the distinct purposes of the different folders created in the online document management system (e.g. the 'work-in-progress' folder, or the 'updated documents' folder) were also continuously re-confirmed during the DCMs. Moreover, members of the design team often openly asked broad questions to each other about:

- where were they in their design (at what stage/amount of progress);
- what was their next area of focus;
- what artefacts would they need from each other;
- when would a particular design artefact be ready for further actions of other design team members;
- what steps had to be followed for coordinating a particular part of the design;
- what already published artefacts could be used for developing the design further;
- how would existing artefacts be validated as up-to-date and relevant for particular design development actions based upon them.

Consequently, design team-wide discussions about the following topics were abundant during the RIBA Stage E:

- How did the issued drawings have to be commented upon, marked-up, and organised in the online document management system?
- What intermediate design artefacts did the practitioners have to produce for achieving the targeted deliverables for different purposes (e.g. market testing, client sign-off etc.)
- What was the targeted content and scope of the artefacts for different purposes?

Often these discussions were in the form of negotiations, where parties tried to convince each other to their proposed stance by revealing the basis of their assumptions about *production, validation* and *use* of the design artefacts in the project. Most of the time, these were related to discipline-specific settings, needs and capabilities. These discussions enabled the members of the design team to appreciate the interdependencies among various practices and mutually adjust them through the collectively formed assumptions around the *production, validation,* and *use* of artefacts for various information needs in the project. One of the examples of this was when the design manager from the main contractor, the architect and the structural engineer negotiated whose responsibility it was to produce and present certain drawings and information in different design documents, and were all seemingly inextricably linked. This is presented as an event (OE 5) below as it also showed how even a seemingly familiar aspect of design (i.e. documentation for setting out[5] information) that takes place in all design projects was subject to negotiations based on a rich base of considerations.

Project OffiBuild – Event 5 (OE 5) - Setting-out information

> *In one of the DCMs a discussion started about who would produce the setting-out drawings in the project. The representative of the structural engineering consultant claimed that they normally did not put dimensions for setting out on their plans. He stated that architects were responsible for the general form of the building and if the architect changed the dimensions of the building and forgot to incorporate these changes in their plans then it would be a problem. The design manager from the main contractor objected to this saying that people on the site should not need two sets of drawings for setting out the structure and therefore this was not acceptable. He stated that the architect had to review the information model against any structural and architectural clashes, and once this was completed then structural plans had to include setting out of dimensions in their plans in line with setting-out dimensions in the model. The design manager argued that as there was only one model, there should have not been any inconsistencies in dimensions. The architect counterclaimed that the structural engineer defined the levels and drainage that is why it was thought the structural engineer had to document the setting-out drawings, but the structural engineer answered that they used the site-layout plan provided by the architect to develop the drainage plans. The design manager ended the discussion saying that the responsibilities were defined in the previously published design deliverables responsibility matrix, and setting-out drawings were the responsibility of the architect. In the following DCM the modeller from the architect claimed that he discovered some discrepancies between the structural and architectural models during the setting out process and these were marked-up and sent to structural engineering consultant's information modeller.*

Towards the end of the observation period, issues such as how to show various levels of detail through a number of interrelated design artefacts, how to cross reference, annotate and eventually update those artefacts became increasingly significant. This meant that the amount of discussions about the *production, validation* and *use* of design artefacts in a

[5] Here, 'setting out' refers to the act of establishing the precise position of the building in reference to some fixed geometrical points on the construction site.

coordinated and consistent way significantly increased. A recurring comment of the client PM in the face of these discussions about coordination and consistency of design artefacts was to establish an automated design approval and commenting system. After being stated a few times by the client PM, this issue was the subject of a larger discussion in one of the DCMs. This is presented as an event (OE 6) below.

Project OffiBuild – Event 6 (OE 6) - Managing the flow of information from comments to approvals and to the site

> *In the OffiBuild project, especially towards the end of the RIBA Stage E the number of documents created increased and their scope became more detailed. The discussions about establishment of clearly-named dedicated folders on the online document management system for different steps in the validation of the artefacts (i.e. folder names such as 'comment', 'mark-up', 'to be checked' etc.) and re-confirmation of the already-existing folders were discussed a number of times in DCMs. The client PM who did not have access to most of the design folders on the online document management system repeatedly asked to be granted some kind of permission to see non-confidential information in order to get a sense of how the progress of design was going and also to provide feedback for the issued artefacts on an ongoing basis. These discussions were generally about setting up automated workflows on the online management system so that the system would automatically manage the role-based control-, validation- and sign-off processes within the team and notify the necessary people in case of changes. The design manager of the main contractor repeatedly claimed that these workflows needed to reflect the internal working procedures of the working parties and therefore needed to be extensively reviewed before setting up. In one of the DCMs towards the end of the observation period this issue arose again. The design manager of the main contractor agreed with other members of the design team that setting up workflows on the online document management system could facilitate the production, validation and use of artefacts in a coordinated and consisted way. He further claimed that there had to be a dedicated document controller in addition to the automated workflows. All other team members supported him saying that a total reliance on system based workflows could be confusing. The design team especially wanted to have a human to manage the interface between the document base, which would be accessible to the design team and the document base that would be accessible to the client PM. Different members of the team stated how they used different systems in the*

previous projects they worked on. The client PM stated that he was happy with anything as long as there was a system in place. He added that such a system should be as much as simple as it could be. The design manager from the main contractor created an action point on this issue. Reflecting on these discussions, the site manager of the main contractor stated that the works on the site were starting soon and a monthly site walk around had to be organised for the design team in order to check that the design intent beyond documented was correctly followed on the site.

This event (OE 6) revealed that the practitioners expected to get assistance from the automated workflows feature of the online documentation system in order to facilitate the tracking of numerous interrelated contents materialised through various design artefacts. Nevertheless, they first needed to discuss the authority and autonomy of this system in order to adjust their assumptions about the process, and therefore the artefacts that would be mediated by it. The experience-based views around using such a process revealed that i) internal working of individual consultants needed to be considered in setting up the workflows; ii) workflows that would be set had to be simple for efficiency; and iii) the ultimate supervision of the system had to be held by a human controller. These views indicated that the practitioners wanted to adjust the automated process according to the concerns of multiple design disciplines, and to have human management of the process. Additionally, the site manager further revealed that even adequately coordinated artefacts had limited capacity in conveying meaning alone, and active involvement of design consultants was encouraged to reflect the original design intent on the site.

The increasing number of documents and their level of detail in the project required various members of the design team to work more closely with the design artefacts produced by others. This also required mutual adjustment of the work arrangements by each design discipline in terms of the media used. An example of this kind of discussion was about the file format type that was used by the structural engineer, who was asked to deliver design artefacts in another file format to better support the activities of the main contractor. However, the discussion exposed some wider considerations that design team had regarding the file format used. This discussion is presented below as an event (OE 7).

Project OffiBuild – Event 7 (OE 7) - .pdf drawings versus .dwg drawings

In one of the DCMs the design manager of the main contractor asked the representatives of the structural engineering consultant to issue drawings in .dwg format in addition to .pdf format. He claimed that their company policy for document *management mandated the use of .dwg files. The site manager also added that the setting-out equipment needed .dwg files to extract coordinates from the drawings. However, the structural engineer claimed that they would be hesitant to issue drawings in .dwg format because once .dwg format was published, users of that drawing could try to do measurements from the .dwg drawings. Through self-reflection, one of the representatives of the structural engineering consultant stated that they could put a warning on .dwg drawings saying that the drawing must not be scaled and .pdf drawings must be checked as primary drawings. Following this, the design manager of the main contractor proposed the structural engineers to lock the .dwg drawings before publishing them. The architect then joined the discussion saying that in case they lock the drawings before publishing then every time a change takes place they would need to re-issue the locked published drawings.*

This event (OE 7) revealed that the material aspects of media of design artefacts had strong connections with a number of discipline-specific and interdisciplinary considerations. Therefore, practitioners had to discuss the material aspects of the media of design artefacts along the needs of their disciplines, and the kinds of situations the artefacts would or could be used in. In this regard, Event OE 7 exposed how materiality of the media of the design artefact had a role in determining the significance of the artefact through the limitations of, and opportunities for, its use.

5.4.3. The LabBuild project

The researcher observed two interdisciplinary design meetings in the LabBuild project. Similar to the EduBuild and OffiBuild projects, in the LabBuild project, planning and tracking of design development were undertaken through the interdisciplinary discussions that focused on the *production, validation*, and *use* of various design artefacts. One different aspect of the LabBuild project was the continuous consideration of ongoing works on the site during these discussions. More specifically, during the observed meetings lots of references were made to the actual situation of the works on the site when discussions that focused on design artefacts were taking place. This included both assuring that the planned work was in line with the needs of the construction teams on the site, and assuring that the produced artefacts reflected the actual situation on the site.

The first observed design meeting in the LabBuild project was held to coordinate the FF&E in the clean rooms with the attendance of representatives from the main contractor's design management team, the clean room sub-contractor, the M&E sub-contractor, the client organisation's team, and the project management company that represented the client. As detailed in Event LE 1 (see Chapter 4), the meeting revealed that it was impossible to develop a general M&E strategy for the outlets in the clean rooms, and the outlets needed to be configured individually considering the needs of the equipment and the particulars of the clean room building systems. For example, when the pipework for the clean rooms was discussed, the participants of the meeting found out quickly that all pipework would need to be designed according to the specific requirements of the individual equipment that was planned. Therefore, the representatives of the M&E sub-contractor asked the client to specify the exact points where the mechanical outlets were needed so that they could address them on a one-by-one basis. The design manager of the main contractor then asked the representatives of the M&E sub-contractor to mark what needed to be specified exactly on the existing drawings. Following this, the representatives of the M&E sub-contractor asked the design manager of the main contractor whether the modelling software enabled them to create 'balloons' (encircled textual annotations) to mark what needed to be specified in terms of mechanical services for each of the equipment that would be installed in the clean rooms. The design manager of the main contractor stated that they could do this but were at the point where they needed the drawings quickly to be able to progress with the clean-room systems construction on the site.

On the same day, during the second observed design meeting, one of the topics of discussion was the external illuminated building sign. External lighting was a part of the design to which a provisional budget was assigned and the illuminated building sign was part of the external lighting package. This was a large, illuminated sign where the name of the building would be written. The representative of the architect brought some photographic examples of different types of signs to the meeting, and presented them to the participants along with a narrative of impact and effect of it on the lighting design scheme. She emphasized the importance of the location of the building sign and its coherence with the rest of the landscape design scheme. On the other hand, the design manager of the main contractor was mainly interested in the cost of various options that the architect presented, and the exact place of the illuminated building sign in order to be able determine an external lighting budget overall. In this respect, he told the representative of the architect that they were already too late in developing the landscape design, and he was not interested in the photographic illustrations, but needed some design proposals and drawings that could be used for costing the external lighting.

Both of these instances showed that, in the LabBuild project, the conversations focused on design artefacts were concerned about the suitability of the artefacts for the needs of the construction works on the site, and the fast-tracked design and build project environment. Therefore, in the LabBuild project, *production, validation* and *use* of the design artefacts were as much related with the needs of the construction teams, and fast-tracking project environment as they were about coordinated creative design. In this regard, design artefacts were needed to drive various aspects of the project such as construction work, project budget and creative design.

Similar to the other two projects, the LabBuild project also used an online document management system where various folders of files for planning and managing the basic validation steps such as commenting, marking-up, reviewing and so on were held. However, in the LabBuild project, another significant criterion in tracking the design development was *consistency* between the ongoing design and the concomitant works on site. For example, the other four meetings that were observed in the LabBuild project were mainly for the synchronisation of the content of the information model with the actual situation on the site. Such an effort was required during the period of observation because the representatives of the client organisation wanted to use the information model to plan their equipment procurement programme, but other members of the design team knew there were inconsistencies between the content of the information model and what was actually already being constructed on the site. Therefore, before the client relied on the information model to plan the procurement of very expensive and high sensitivity equipment, the design team had to synchronise the information model with the work on the site. In this respect, tracking of the design development was significantly shaped by the actual ongoing construction. As a result, *production, validation,* and *use* of the design artefacts was shaped by this particular design-tracking criterion and demonstrated in the observed conversations about various design artefacts (e.g. columns on the site were built outside of the allowed tolerances, and therefore many drawings needed to be updated according to the situation on the site, beginning with updated structural drawings). Moreover, in order to achieve this synchronisation, a laser scan survey was planned on the site to reflect the as-built situation of the critical areas for model precision. This required holding further conversations focused on the laser scan (i.e. its results as a survey document) and its connections with other design artefacts (e.g. the information model, published drawings etc.) in order to establish how all these interrelated artefacts had to *be produced, validated* and *used*. Overall, in the LabBuild project, all the discussions that were focused on the *production, validation,* and *use* of the design artefacts involved a sense of the site works and the fast-tracking project environment which was different from the two other observed projects.

Another instance that was observed in the LabBuild project revealed the importance of maintaining the already-established procedures for the design artefacts, so as not to disturb the coordination needed for design development. In the second observed design meeting, one of the topics of discussion was the signage design strategy in the building and the expectations of the client. The representative of the client indicated that the client organisation had a standard coding system for the room numbers in its buildings. The representative of the architect requested that document to use in the design of signage. But the design manager of the main contractor stated that no matter what kind of coding system was used for the signage design, the coding of the areas in the project design documents had to remain the same as established previously. This statement showed that it was not only the consistency of the assumptions held by various practitioners that was important, but also the consistency of the rules of materialisation used in the *production, validation* and *use* of design artefacts in coordinating the design artefacts in the project.

5.5. Discussion and Concept Development

This chapter adopted an empirical focus on the active role of design artefacts in the accomplishment of interdisciplinary design development practices. Evidence from practice was presented in order to establish how design artefacts were used in interdisciplinary interactions and how they gave sense to practicing. The aim of this chapter has been to provide an explanation of how design artefacts '*informed*' the interdisciplinary design development and contributed to making sense of what to do and what ought to be done.

The chapter is structured around the different kinds of ways that design artefacts entered the observed practices. The findings suggest that the design artefacts were inextricably entangled with meaning-making in interdisciplinary design development. Artefacts established connections among various practices in time and space through their persistent material properties, and assured continuity and consistency among various practices by enabling enactment of *information* through material representation of certain aspects of design work. Thus, they were essential for making sense of interdisciplinary design in consistent and coherent ways. Nevertheless, design artefacts were limited representations of certain aspects of the building and design process. Therefore, they owed their significances to interdisciplinary conventions and shared understandings that needed to be established and continuously re-confirmed around them (i.e. symbolic properties). Even in the presence of these conventions and shared understandings, the ultimate meaning of the design artefact highly depended on the particulars of the situation it was used in, and individual views of those who were working with it. Therefore, contributions of design artefacts in interdisciplinary design development depended equally on individual and collectively established understandings about the situations and the design artefacts. All these roles that design artefacts accomplished were instrumental in achieving a *shared sense of purposefulness,* and therefore revealed what '*purposefulness*' might mean in interdisciplinary design development practices as elucidated below.

5.5.1. Design situations, design artefacts, and design information

The relationship between *design situations*, *design artefacts* and *design information* is entangled in the sense that it is difficult to explain one without referring to the other two as they all enact each other. Therefore, an explanation of how *design artefacts* give sense to practicing, define '*purposefulness*', and contribute to the accomplishment of interdisciplinary design development requires establishing this entanglement.

First, the findings suggest that *design artefacts* were abundant in the observed practices and were essential for enacting *design situations*. More specifically, they were frequently referred to, and actively used in interdisciplinary design discussions (as detailed in Sections 5.2 and 5.3). *Design artefacts* were referred to, and employed, in order to remember, remind, argue, explore, ask, plan, track and so on. Therefore, it can be argued that the practitioners depended on *design artefacts* (i.e. symbolic meaning of *design artefacts*) for thinking and talking about various aspects of the design project. In Ramiller's (2012) words, interdisciplinary design development practices were 'psychomaterial' in the sense that the practitioners made sense of the constituents of the design project in terms of *design artefacts*. More specifically, it is argued that *design artefacts* were not separate from, or inside, the *design situations*, but they were constituents of situations through their power of enactment of various configurations of discipline-specific views (i.e. roles), design stages (i.e. temporality or process of the project), and parts and functions of the buildings (i.e. design product). Therefore, *design artefacts* were interwoven with the interactions involved them in the sense that their material properties and symbolic meanings informed the situations, contributed to the constitution of the situations, and therefore assisted practitioners in establishing a shared understanding of what the situations were about. *Design artefacts* achieved this through creating points of focus to organise the meanings around (Wenger 1998). Certain aspects of *design artefacts* came to the fore in certain *design situations* and enabled meaningful communication about a highly notional area of work among people who were alien to each other's considerations. Therefore, *design information* enacted through *design artefacts* are essential constituents of interdisciplinary *design situations*. For example, Table 5 shows various examples of situations in which '*design artefacts*' were referred to make particular statements which enacted '*design information*' and thus, framed the '*design situation*'. Figure 12 illustrates how practitioners think and talk through *design artefacts* that they associate with their understanding of various aspects of design. In Figure 12, practitioners hold a conversation through the references to *design artefacts* and jointly develop their understandings about various aspects of their discipline-specific design. This enables further development of design as *design artefacts* and enacts further interdisciplinary *design situations* based on them.

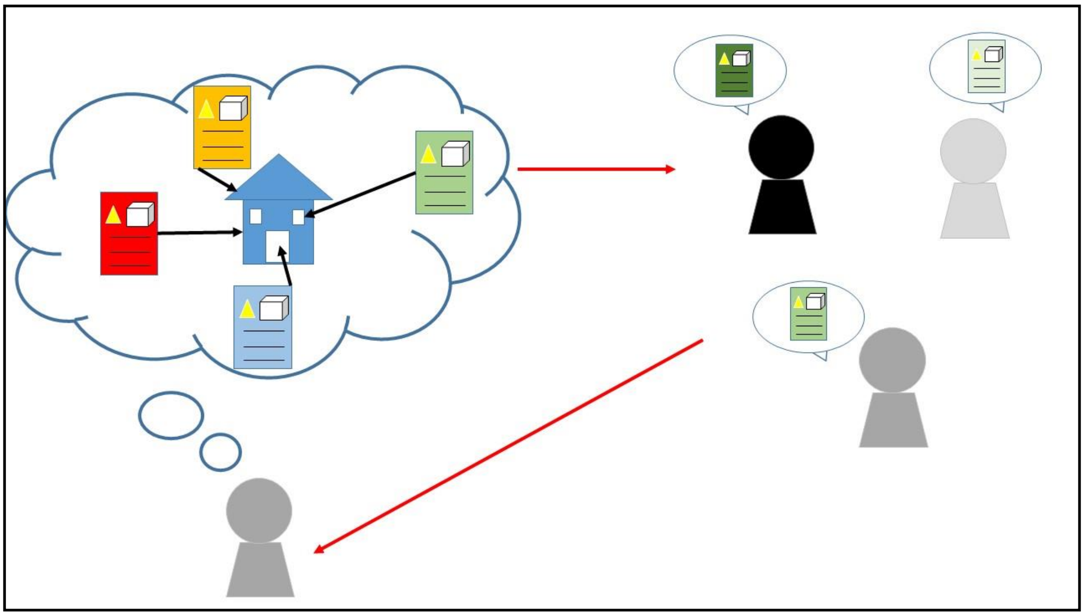

Figure 12 - Centrality of design artefacts in thinking and talking about design

Second, *design artefacts*' power of focusing the attention to particular points to organise the meanings (i.e. intermediary role) depended on the presence of shared understandings of the material and social conventions around the design artefact. In other words, the potential significance of artefacts first needs to be established and mutually adjusted before being useful in interdisciplinary communication. These conventions were established (e.g. Event OE 5) and continuously re-confirmed (e.g. the 'updates' section of the DCMs in the EduBuild project) through a mixture of past individual and shared experiences as well as explicit questions asked in the observed situations (e.g. the questions asked to the M&E engineer about the ventilation calculations of the auditorium in the OffiBuild project). The social and material conventions about a design artefact were crucial for the enactment of *information* because it was these conventions that framed the enactment by signalling the limits and scope of the *information* that could be based on the artefact (e.g. the agenda item about the use of 'roof duct and pipe layouts' to finalise step-overs in the EduBuild project). Such conventions were required for the meaningful use of *design artefacts*, because a design artefact is always an abstract representation of a fragment of reality that was materialised from a particular point of view. Therefore, there are always assumptions embedded in the making and use of a particular design artefact which needs to be known by various members of the design team to accomplish meaningful interdisciplinary communication.

Third, it can be argued that the ongoing process of establishing these conventions through specification of artefacts was indeed the process of negotiating local (i.e. discipline-specific) *information* needs and corresponding local *material arrangements* (i.e. ways of working). This was, for example, evident in Events OE 5, 6, 7 and the continuous consideration of the situation on the site in almost all artefact-related discussions in the LabBuild project. Therefore, it can be argued that establishing the material and social conventions about *design artefacts* corresponds to the alignment of practices of various disciplines, and the alignment of the project practices with the practices of the external environment (e.g. using documentation requirements for a planning application submission in directing the design development in the OffiBuild project). In Figure 13, practitioners from different disciplines discuss their specific needs that are based on their discipline-specific *information* needs and *local material arrangements*, and acknowledge the specific needs of the external actors – such as the city council's planning department (symbolised with white text, triangle, and cube for different disciplines, and green text for the external actor). The resulting artefact carries traces of different needs that must be addressed. Hence, *information* value of the artefact for multiple parties is built in the artefact.

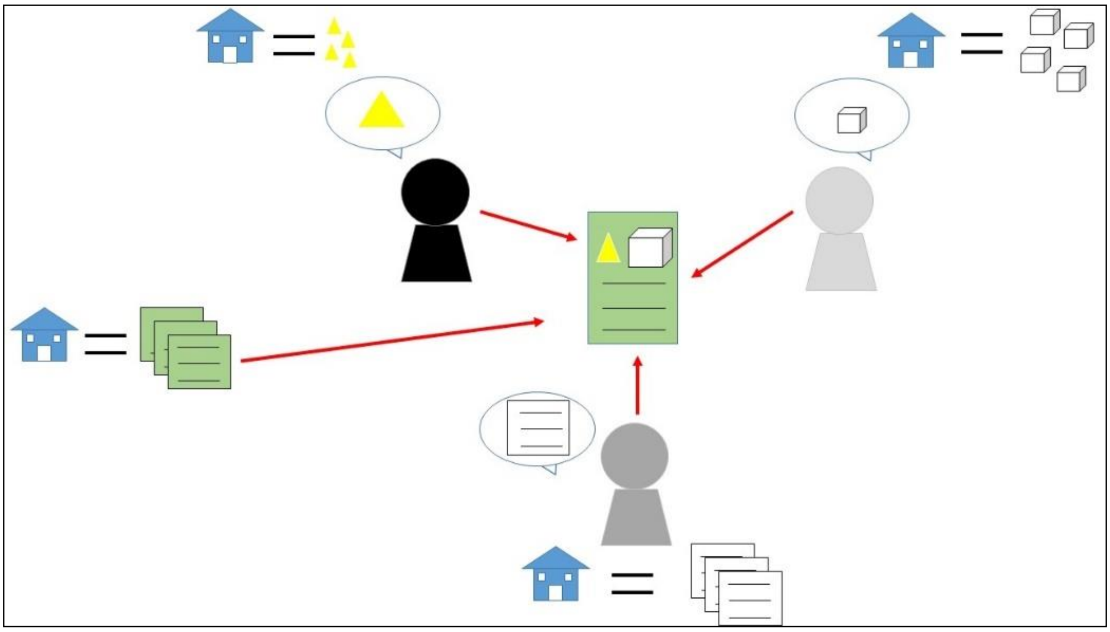

Figure 13 - Establishing conventions around design artefacts corresponds to negotiation of local needs and arrangements

Having a shared understanding of the social and material conventions about *design artefacts* does not mean that representatives of different disciplines enacted the same *information* through the use of the same artefact in a given situation (e.g. Event OE 1). On the contrary, the same artefact meant different things to different individuals due to their differences in professional backgrounds, knowledge and concerns. Nevertheless, a continuous interdisciplinary effort to establish or re-confirm the social and material conventions about the *design artefacts* was present at all times in order to assure that the *information* enacted through the artefact in a given situation were consistent. In this respect, even if the symbolic meanings of the *design artefacts* were known to some extent by the practitioners, due to a multiplicity of individual or shared pasts that complement them, the conventions still needed to be continually re-confirmed or re-established in various instances in order to be consistently used in particular situations (e.g. the 'lighting scheme' was an aesthetical concern for the architect of the LabBuild project and a cost-related concern for the design manager of the main contractor). Figure 14 illustrates practitioners from different design disciplines enacting different *information* through the use of a same *design artefact* based on their particular backgrounds, foci, and skills.

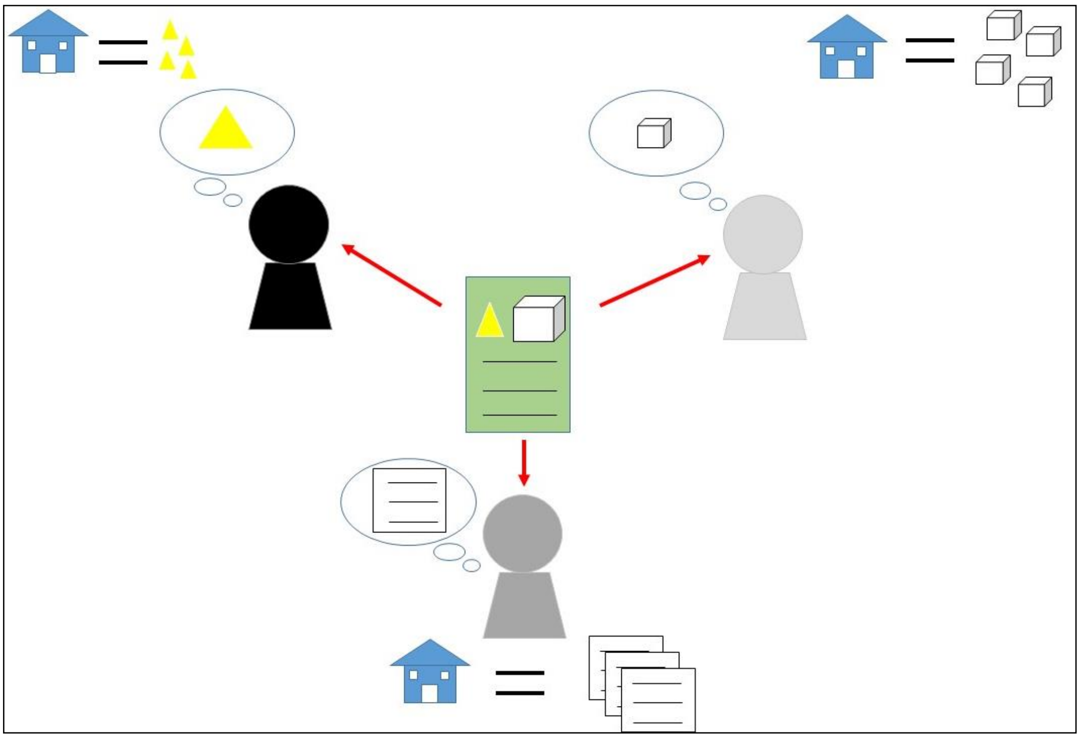

Figure 14 - Practitioners from different disciplines enact different information using the same design artefact

Fourth, *design information* was enacted according to the particulars of the *design situation* in which the artefact was referred to or used. A single *design artefact* could mean many things to practitioners. It was both the social and material conventions, and the particulars of the situation that complemented the abstract character of the *design artefact* which enabled enactment of consistent *design information* (e.g. the use of site plan for a variety of purposes in different situations in the OffiBuild project). Figure 15 illustrates the interdisciplinary use of a same *design artefact* in different *design situations*. In different *design situations*, practitioners enact *different information* through the use of the *design artefact* (symbolised with different colours for each situation – i.e. white, red, and yellow) based on the particulars of the *design situation*.

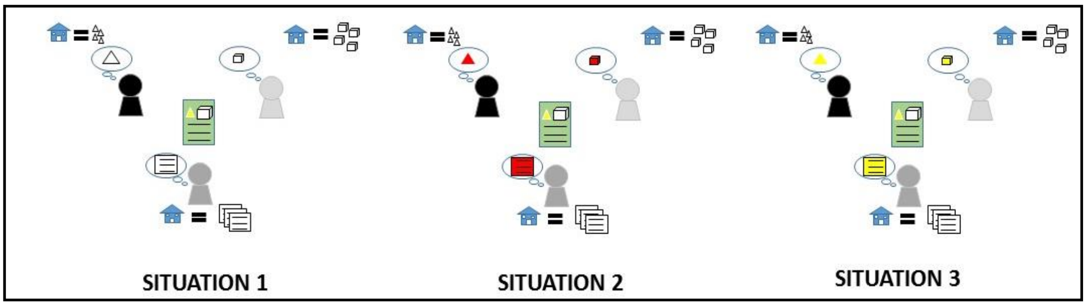

Figure 15 - Design information was enacted according to the particularities of the design situation

Finally, *design situations* determined the information needs of practitioners which then were articulated as specifications of *design artefacts*. More specifically, upon the achievement of a *shared sense of purposefulness* about design issues, the resolutions of the issues were always planned around *design artefacts* which were specified in terms of material aspects (i.e. media and content), validation processes, and intended uses of the artefacts (e.g. see for example 'previous minutes' section of the DCM agenda of the EduBuild project provided in Appendix 2). It can be argued that the discussions around the design issues pursued a consistent understanding of *what* needed to be done by each practitioner in order to solve the design issue (i.e. *establish a shared sense of purposefulness*), and the following discussions about *design artefacts* pursued a consistent understanding of *how* it needed to be done. In other words, the discussions about design issues established a consistent understanding of the *information* needs of various members of the design team, and the following discussion aimed to establish what kind of *design artefacts* and accompanying social and material conventions were needed to satisfy those needs.

In this regard, *design artefact* specification processes enabled the practitioners to test or re-confirm whether their individual understandings of *purposefulness* were in line with others. Activities such as *production, validation* (i.e. reviewing, marking-up, commenting on), and *use* of *design artefacts* are practices of checking the previously established *shared sense of* *purposefulness* in its material form, and create opportunities for amending or refining them when discrepancies were noticed. This argument can be justified by the consideration of the criticisms made by the practitioners after reviewing artefacts produced by others as part of the validation process. It could either be a case that i) practitioners thought that they achieved a *shared sense of purposefulness* discursively but realised that they did not; or ii) the materiality presented in the *design artefact* could expose novel dimensions of the design issue so further discussions about the design issue would be required to refine the *shared sense of purposefulness* and discuss novel *information* and artefact needs.

Therefore, the *production, validation*, and *use* of *design artefacts* were the material manifestations of the *shared sense of purposefulness*, which indeed enabled the practitioners to test and/or refine it through the discoveries that could only be made through talking about and working with those artefacts. When these discoveries were made, then further discussions about those discoveries would re-establish a *shared sense of purposefulness* about the new design situation. This argument also provides an explanation of why familiar/expected design issues did not require much design discussion, nor artefact-focused discussion whereas the unfamiliar/unexpected ones required extensive design-related and artefact-focused discussions. Such an understanding of the continuous and entangled relationship between *design situations*, *design artefacts* and *design information* correspond to a description of design development in terms of *design artefacts*. This is illustrated in Figure 16 below.

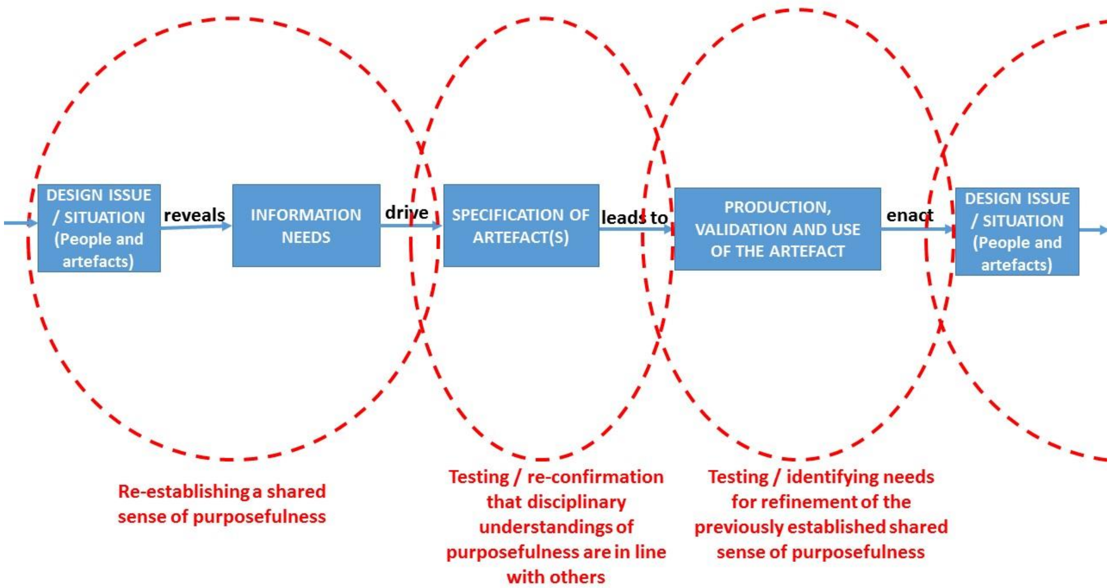

Figure 16 - Interdisciplinary design development as the entanglement of design situations, design information, and design artefacts

5.5.2. Shared sense of purposefulness and the concept of purposeful artefact

The previous section implies that *design situations*, *design artefacts* and *design information* are inextricably entangled in interdisciplinary design development practices in the sense that they continuously enact each other, and hence, enable the development of design (see Figure 16). Ultimately, this can be seen as a continuous 'process of alignment' (Nicolini 2012) between interdisciplinary design development practices, and *design artefacts*, in the pursuit of sustaining a *shared sense of purposefulness* (see Figure 17 below).

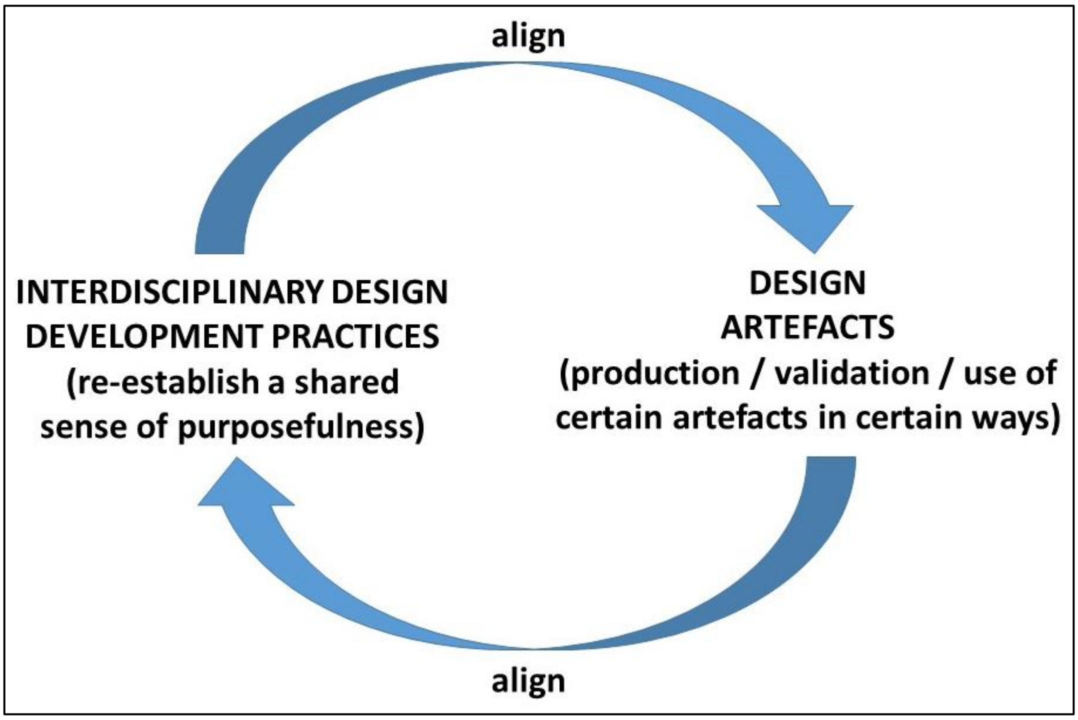

Figure 17 - Interdisciplinary design development as the alignment of interdisciplinary design development practices, and design artefacts

Interdisciplinary design development practices were shaped by *design artefacts* that established connections in space and time among various interrelated practices, and carried meanings among them. At the same time, *design artefacts* were shaped by the interdisciplinary design development practices to efficiently accommodate various evolving needs that coincided and discussed in interdisciplinary design development practices.

This explanation implies that design artefacts that were involved in interdisciplinary design development were always '*purposeful',* thus, leading to the concept of '*purposeful artefact'*. The concept of '*purposeful artefact*' suggests that *design artefacts* that were involved in interdisciplinary design development were always based on a sense of what is needed, and how to achieve it (i.e. *a shared sense of purposefulness*). *Design artefacts* gave sense to practicing (or more specifically gained their representational, intermediary and performative powers) not only because individuals had past individual professional experiences of working with them, but mainly due to the shared past and present of multiple parties established through interdisciplinary interactions. Therefore, *design artefacts* that were involved in interdisciplinary design development were made '*purposeful*' through interdisciplinary interactions at least in the following three senses:

- Tailored artefacts: What artefacts needed to be *produced*, how they needed to be *validated*, and *used* were decided based upon a *shared sense of purposefulness* around the design issue/situation. Therefore, unique issues were addressed with uniquely tailored artefacts.
- Usable artefacts: The artefacts were 'usable' for the parties that had a stake on the *information* aimed to be enacted through their *production*, *validation* and/or *use*. More specifically, they considered the discipline-specific ways of working/material arrangements of the concerned parties.
- Useful artefacts: The artefacts were 'useful' for the parties that work on the same design issue, in the sense that they considered the discipline-specific *information* needs of a variety of disciplines that worked on the same design issue.

In return, the '*purposefulness*' of the *design artefacts* played an essential role in interdisciplinary *design (development) situations* in that they facilitated mutual understanding in the design team, and framed 'what to do next', and 'what ought to be done'. They enacted *situations* that gave a thrust for the advancement. In this respect, as showed in Figures 16 and 17, establishment of a *shared sense of purposefulness*, and the *production, validation,* and *use* of design artefacts mutually enacted each other, leading to the consistent and coherent development of interdisciplinary design.

CHAPTER 6. INTERDISCIPLINARY MODEL-BASED WORKING IN PRACTICE

6.1. Introduction

All the observed projects used digital information models to varying extents during design development. However, in the majority of the observed interdisciplinary meetings that were concerned with design development, the models were not present or actively used, nor were they mentioned often during the meetings. The references to, or the use of models in these meetings were present but rare. The ongoing fieldwork revealed that interdisciplinary model-based working required interdisciplinary discussions and meetings to be coordinated. These discussions and meetings were distinct and largely separately held from the ones related to design development, thus, raising an interest about the role and significance of model-based working in organising interdisciplinary design work. Chapters 4 and 5 provided explanations regarding how practitioners made sense of what to do, and what ought to be done in interdisciplinary design development, and the active role of design artefacts in this respectively. This chapter seeks to establish how model-based working fit into, covered, and/or amended the sense of what to do, and what ought to be done to develop the design.

The observed projects had different contractual requirements about the BIM use in the project and they also showed significant differences in the ways models were positioned within the wider organisation of the design project. However, in all the observed projects, interdisciplinary model-based working was present. More specifically, all the observed projects involved the use of digital information models by more than one stakeholder, and models from at least two design disciplines were exchanged and combined in the projects for the purposes of design development. Consequently, interdisciplinary model-based working was a matter of concern for all the observed projects, and the concerns about model-based working surfaced in the observed interdisciplinary interactions in a number of ways.

This chapter builds upon the observed model-related interdisciplinary discussions and meetings (e.g. model coordination and clash detection meetings) as well as interviews and informal communications with practitioners on interdisciplinary model-based working. Modelling was an activity held individually in offices, therefore interviews and informal communications about interdisciplinary model-based working were used to extend and validate the observations.

The governing research questions of this chapter are:

- Research Question (RQ) 3: How is interdisciplinary model-based working accomplished in practice? How do people make sense of interdisciplinary model-based working?
- RQ 4: What are the connections between model-based working practices and other interdisciplinary efforts?

Following Nicolini (2012), the chapter adopts an empirical focus on 'the oriented and concerned nature' of interdisciplinary model-based working practices for the presentation and analysis of the findings (see also Section 3.3.2 in Chapter 3 for a discussion of the adopted empirical focus). As already stated in Section 4.1 (Chapter 4), Nicolini (2012) argues that the accomplishment of a practice by practitioners is driven by a sense of 'what to do', and 'what ought to be done'. Consequently, the aim of this chapter is to bring forward the 'lived directionality' (Nicolini 2012), which drives interdisciplinary model-based working, and hence, enables 'making sense of', and 'organising' it. Key to studying the 'oriented and concerned nature' of practices is to explore the 'practical concerns and matters': the ways the object of work is experienced by practitioners (Nicolini 2012).

According to the practice-based approach adopted in this study, 'organising' is continuously accomplished through the activities performed in everyday practices. Nevertheless, practices are never isolated or stand alone, but always connected to each other through people and objects. Therefore, to bring forward the 'lived directionality', it is also essential to explore how and why practices are interconnected. This methodology of moving among different levels of organising has been referred to as 'zooming-in' and 'zooming-out' in Sections 3.3.1 and 3.3.2 (Chapter 3).

Figure 18 below depicts how the chapter addresses RQ 3 and RQ 4, and contributes to the study. The chapter first explores what mattered to practitioners; what they worried and cared about in terms of model development and use, in order to address RQ 3 (shown as 'zoom-out x1' and 'zoom-in' in Figure 18). Then the chapter associates these findings with the wider organisation of design work in addressing RQ 4 (shown as 'zoom-out x2' in Figure 18).

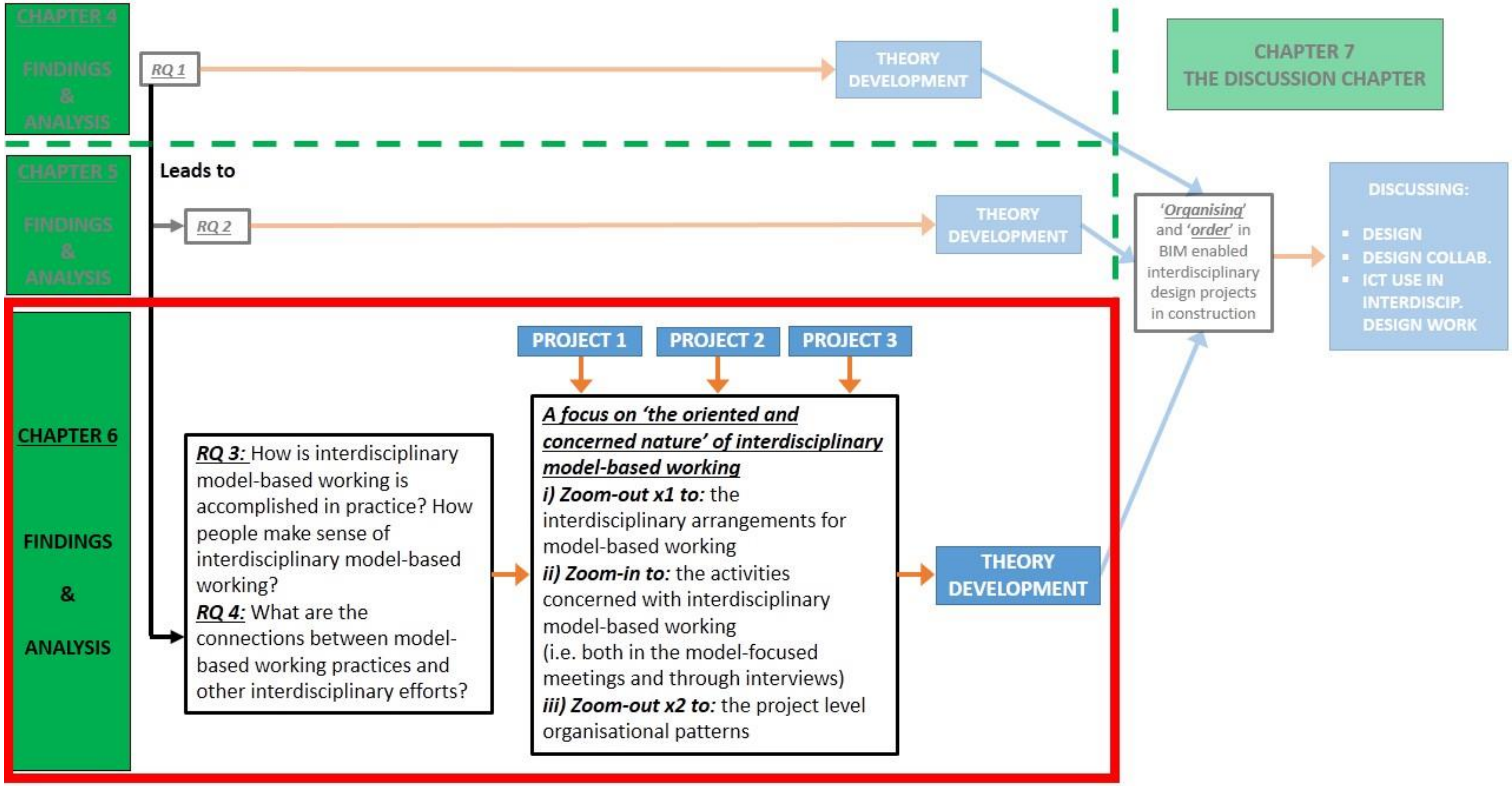

Figure 18 - The position of Chapter 6 in the study, and its contribution to theory development

Figure 19 depicts the structure of the chapter in terms of its strategy for approaching to the empirical phenomena of interest, and developing theory from findings. As shown in Figure 19, the chapter starts with presenting first-order empirical findings from each of the studied projects. The findings from each project are presented separately considering the significantly different model-based working practices observed in each project. The first-order empirical findings about 'the oriented and concerned nature' of interdisciplinary model-based working are presented at three different levels of organising (i.e. shown as 'zoom-out x1', 'zoom-in', and 'zoom-out x2' in Figure 19).

For each project, first a general overview of the project-specific context of model-based working is presented to reveal the scope and extent of model-based working ('zoom-out x1'). Following this, the 'orientation' of the observed interdisciplinary interactions (i.e. activities) that were concerned with model-based working are presented to expose what mattered to practitioners, and what they worried about during these interactions (zoom-in). Afterwards, the empirical findings from the level of interrelated practices are presented in order to reveal how model-based working was experienced in the wider organisation of the observed projects (zoom-out x2). These first-order empirical findings are then thematised into two overarching 'practical concerns', which provide an explanation of what was it that was achieved through interdisciplinary interactions concerned with model-based working. Following this, a theoretical explanation about the 'lived directionality', which drove the interdisciplinary model-based working is developed based upon the established themes of 'practical concerns' (see Figure 19). It is argued that this 'lived directionality' enabled practitioners to make sense of what to do, and what ought to be done in interdisciplinary model-based working. Thus, made the model-based working practices 'intelligible' (i.e. meaningful), and their 'organising' possible. In Section 6.6 a discussion is held in order to develop an explanatory organisational concept that addresses RQ 3 and RQ 4.

First order observations and other communications

	Interdisciplinary arrangements about model-based working (zoom-out x1)	Activities of interdisciplinary model-based working (zoom-in)	Project-level organisational patterns (zoom-out x2)
	An overview of the project specific context of model-based working - What were the interdisciplinary arrangements around model-based working?	**Orientation of the interdisciplinary interactions related to model-based working** - What were practitioners occupied with? - Where did practitioners direct their efforts?	**Connections between interdisciplinary interactions about model-development and interdisciplinary interactions about design-development** - What are the connections between model-based working practices and other interdisciplinary efforts?
EduBuild Project	*SECTION 6.2.1*	*SECTION 6.2.2*	*SECTION 6.2.3*
OffiBuild Project	*SECTION 6.3.1*	*SECTION 6.3.2*	*SECTION 6.3.3*
LabBuild Project	*SECTION 6.4.1*	*SECTION 6.4.2*	*SECTION 6.4.3*

Second order themes & theoretical explanation

THE ORIENTED AND CONCERNED NATURE OF THE INTERDISCIPLINARY INTERACTIONS RELATED TO MODEL-BASED WORKING

Themes of practical concerns, and the lived directionality of the interdisciplinary interactions related to model-based working
- Practical concerns of working 'in' the model, and working 'with' the model - The lived directionality as the 'continuous re-alignment of working 'in' the model, and working 'with' the model'
SECTION 6.5

ORGANISING INTERDISCIPLINARY MODEL-BASED WORKING

Discussion and concept development

SECTION 6.6

Research Question 3: How is interdisciplinary model-based working is accomplished in practice? How people make sense of interdisciplinary model-based working?

Research Question 4: What are the connections between model-based working practices and other interdisciplinary efforts?

Figure 19 - Data, analysis, and theory development structure of Chapter 6

6.2. Interdisciplinary Model-based Working in the EduBuild Project

6.2.1. An overview of the project-specific context of model-based working (zoom-out x1)

Among the observed projects, the EduBuild project was the most ambitious in terms of model-based working. At the outset, the project aimed to develop a fully-coordinated integrated design model consisting of various discipline-specific models (e.g. an architectural model, a structural model etc.) with the purpose of using the design model as the baseline for model-based cost management, scheduling, construction as well as for operations and maintenance. The client had a BIM-literate estates team which had previously completed a BIM-enabled new-build project called 'Phase 1'. Design team members also had working experience in BIM-enabled projects. Most of them had either worked in the previous phase (i.e. Phase 1) of the observed project or in other BIM-enabled projects. The project had detailed conventions for model-based working (e.g. responsibility matrices for the objects in the model, naming conventions for object families etc.) as well as a detailed Employer's Information Requirements document describing the parameters to be provided by specified stakeholders for each of the objects in the model. This information was mainly documented under a BIM protocol which was part of the contract both for the main contractor and the design consultants. A commercial modelling platform (MP) that had architectural, mechanical-electrical (M&E) engineering, and structural engineering packages was chosen by the client to be used as the shared BIM platform in the project. The presence of different packages of the same platform allowed interdisciplinary model-based working, or more specifically software interoperability. Nevertheless, it was observed that there were various ongoing interdisciplinary interactions regarding the development and use of models. In the following sub-sections, first the orientation of interdisciplinary interactions related to model-based working is presented (i.e. zoom-in). This is followed by a further zoom-out to the level of interrelated practices in order to establish a connection between the observed interdisciplinary interactions and the wider organisation of the project in relation to model-based working.

6.2.2. Orientation of the interdisciplinary interactions concerned with model-based working (zoom-in)

Over the observation period of the EduBuild project, there were various modes of ongoing interdisciplinary interactions regarding model-based working. These included i) ongoing references made to model-based working during DCMs; ii) clash detection and model coordination meetings in which models developed by different disciplines were actively used and were the central theme of the discussions; and iii) remote interactions such as calling or sending e-mails with screen-shots from discipline-specific models in order to clarify a potential mistake, or to highlight a confusing component noticed in a model. Besides, interviews with the members of the design team revealed that a significant amount of interdisciplinary discussions took place also before the observation period started in order to achieve "*some kind of consensus*", as stated by a representative of the architect. These discussions were about what needed to be modelled and how, in the project. For example, according to the interviewees, especially at the beginning of the project, it took some time to define what should be classified under the 'generic model category' and what not. Similarly, interdisciplinary discussions were held about how to schedule the curtain wall in the model at the beginning of the project. Nevertheless, these discussions were fewer compared to the ones that were held at the beginning of the Phase 1 project, the predecessor of the EduBuild project which was designed mostly by the same stakeholders (i.e. the architect, the client team, and the M&E sub-contractor were same). In the following, the interdisciplinary interactions concerned with model-based working are described to reveal their 'orientation'. The descriptions are presented according to the type of the meeting in which the interactions were observed. First the interactions that took place in the DCMs of the Edubuild project are presented followed by those that were undertaken remotely. Finally, the interactions that took place in the clash detection and model coordination meetings are presented.

<u>Interdisciplinary interactions concerned with model-based working in DCMs</u>

Over the ten months long observation of the EduBuild project, only in one DCM the information models were actively used for the discussion of coordination requirements of the rooms in the corners of the floors (see Event EE 2 in Chapter 4). Apart from this instance, the models were never actively used in DCMs, and they were only shown a couple of times to quickly point at certain parts of the building. All other instances that involved models or modelling in DCMs were references to models or model-based working. The references made to model-based working during the observed DCMs mostly involved quick questions in relation to the coordination of a specific design issue or the design package (e.g. ground floor lightings). These questions were generally about i) whether a certain part of the design was in a discipline-specific model (e.g. architectural model); and ii) whether the current data in the model were appropriate for the specific coordination requirements of the design issue or design stage at hand. Therefore, although quick, these references enabled ongoing re-confirmation of the accountability (i.e. appropriateness) of the evolving design data in the model.

However, these references made to model-based working during DCMs were not only about model development or model-based coordination because as one of the interviewees said, the design in the EduBuild project was "*still mainly based on 2D drawings but [only] coordinated through a 3D model*". Therefore, in the EduBuild project, there has been a constant interdisciplinary effort to manage the differences and interplay between the models and the design artefacts published through them (i.e. 2D drawings, material schedules etc.). This meant that during DCMs, references made to models indeed aimed to reveal two things. First, they aimed to interrogate the presence and reliability of the current data in the models for the coordination of certain design issues and packages as explained above. Second, and connected to the first point, these questions aimed to reveal what design artefacts (i.e. 2D drawings, material schedules etc.) could be reliably issued through the current models. For example, in one of the DCMs, the representative of the M&E sub-contractor asked the representative of the architect to update the architectural model and re-issue the 'Reflected Ceiling Plans' in order to accommodate the periscope grills which were recently modelled by the M&E sub-contractor's team. Therefore, in the EduBuild project, having a part of the design in the model was one consideration, and issuing design artefacts related to that particular part of the design through the model was another consideration.

This aspect was visible in the wording of both the agenda items and verbal references made to models by practitioners. For example, in one of the DCM agendas, it was stated that "*Trench heating active/dummy grille lengths indicated in model. [M&E sub-contractor] to issue drawing mid/end next week. Sample grille on site for review.*" This agenda item clearly differentiated between model development and issue of design artefacts through it. In this example, first the model was developed followed by the issue of design artefacts through it. However, this was not always the case. The M&E sub-contractor developed its design elsewhere in 2D and then modelled it in the shared platform, although this was very much criticised by the architect, the main contractor, and the M&E consultant. Therefore, the agenda items related to the M&E design could appear in the other way round: "*Roof duct & pipework layouts issued – will be uploaded into model today*". Moreover, the difference between model development and issue of design artefacts through it, became more and more significant towards the end of the observation period. Towards the end of the observation period, with the increasing installation of finishes on the site, more and more detailed 2D drawings were asked to be issued in DCMs. Some of them were automatically generated through the model but most of them required further detailing (i.e. on top of the level of detail included in the model) or the measurements from the site to adequately communicate the original design intent.

Furthermore, occasionally in DCMs, the consistency between the issued design artefacts and up-to-date models were discussed. This was because models had continuously been changing and the previously issued drawings had to be re-issued when related parts of the models were updated. Therefore, sometimes, when practitioners had to work with the artefacts that were previously issued by others, they had to confirm that they were working with an up-to-date version of the drawing. These confirmations resulted in discussions regarding which drawings were up-to-date, which needed to be updated, and occasionally whether a systematic approach would be possible to keep the previously issued artefacts up-to-date with evolving discipline-specific models. This interplay between model and issue of other artefacts sometimes led to further confusing situations. For example, in one instance the representative of the architect stated that his team had been informed that the M&E sub-contractor measured dimensions from the Reflected Ceiling Plan (RCP) issued by them in order to install chilled beams in one of the rooms. He stated that this did not make sense because the architectural team used the chilled beam positions in the current M&E model when producing that RCP. This required a conversation and further checks regarding which version of model was used to produce the RCP and whether the RCP was updated according to the last model issued by the M&E sub-contractor.

Additionally, occasionally DCMs hosted some discussions about the special modelling requirements regarding certain parts and functions of the building which presented some irregular aspects. In such cases, practitioners specifically mentioned the need for modelling some particular aspects of these parts or functions, and the required level of modelling. One such case was the coordination of mechanical and electrical services above the ceilings in the rooms located at the corners of the floors, and another was the coordination of the services above the ceiling in the boardrooms (see Events EE 1 and EE 2 in Chapter 4). In these cases, for example, all the piping connections of the chilled beams were asked to be modelled to enable high precision coordination whereas in most of the other instances of chilled beam installation, such level of detail of modelling was not required.

Finally, in the DCMs of the EduBuild project, sometimes practitioners held discussions regarding the modelling-related procedures introduced by the client organisation. This kind of conversations was mainly held during the 'clash detection and model coordination meetings' which were attended also by the representative of the client. However, it was observed that the members of the design team held additional conversations related to modelling procedures in DCMs, and expressed their critical thoughts regarding the procedures imposed by the client team in the absence of its representatives. For example, towards the end of the observation period, the client organisation announced that the 'snag lists' would be created and followed using a separate BIM software plug-in developed for integrating the design model with the site works (i.e. a software extension to connect the office-based design modelling to the site teams). In one of the DCMs, representatives of various disciplines discussed this development and established it as a positive (e.g. it was thought that having all snag lists together was a good development) and negative sides (e.g. it was thought that snag lists might not be used as efficiently as they could when one knew that they were visible to the other members of the project team).

<u>Remote interdisciplinary interactions concerned with model-based working</u>

There were ongoing individual remote interactions among practitioners. These were performed when various parties could not make sense of other disciplines' models, or thought that there was a problem with the model of another discipline. The interviews with the practitioners revealed that in such cases it was usual for the practitioners to take a screen-shot, attach it to an e-mail, and ask for clarifications, or alternatively to just give a call to the relevant party(ies) for a clarification. For example, see the excerpt below from an interview with one of the representatives of the architect:

> "*We don't have to think about it [other stakeholders] because of the way [the software] pushes you to model in specific ways. As we follow the built-in families etc., they can interrogate the model we share. For example, they can select a wall and then see it is a plaster board and what kind of insulation it has etc. If we modelled everything under generic models, they might be confused. We get very little questions from them. Occasionally we do get questions but it is generally where our modelling is slightly off. For example, in some tricky bits around the lecture theatre where there are lots of walls going from slab to slab… because there are several slab levels... We designed it in plan so at some points there are some gaps between slabs and walls. They sent us a screen shot asking whether there really is a gap there or whether the wall goes all the way down to the lower level slab? and we answered. But they have a sense because they have done this before. This is generally that sort of things we coordinate with them*".

The interviews with practitioners also revealed that the amount of remote interactions gradually decreased since the beginning of the project, and also from the Phase 1 project to the Phase 2 project (i.e. the EduBuild project).

<u>Interdisciplinary interactions concerned with model-based working in clash detection and model coordination meetings</u>

In the EduBuild project, there were meetings specifically focused on the modelling-related issues. These meetings were held to perform automated clash-detection exercises in the models as well as to have discussions regarding general issues concerning model coordination. They were attended by all the active members of the design team who had been currently interacting with the model (i.e. including the design manager of the main contractor) and the representative of the client. Although these meetings were originally called 'clash detection meetings' by the members of the EduBuild project team, a significant part of them involved conversations about wider issues regarding development and use of models; and therefore, here they are called 'clash detection and model coordination meeting' (CDMCM). CDMCMs were originally planned to be held monthly, however they did not have a fixed interval and were mainly scheduled in consideration of the amount of development in discipline-specific models since the previous meeting. This was to ensure that the models were meaningfully more-developed than the ones used in the previous meeting for clash detection.

There were significant differences between the CDMCMs and other face-to-face interdisciplinary meetings for design development that were held in the EduBuild project. First, the participants of CDMCMs were largely different than the ones who regularly participated in DCMs and coordination workshops. Although representatives from the architect who attended all kinds of meetings were largely the same, the representatives of the M&E sub-contractor and the structural engineering consultancy who attended CDMCMs were largely different. Second, in CDMCMs, the vocabulary used was very technology-centred with lots of terms adopted from design software and document management system such as objects, families, worksets, models, names of different file formats, folders, clash detection rules etc. The strategies employed during these meetings were mixed between efforts aimed at understanding the technology, and for management of it to support design development tasks. Purely technological discussions were held on an ongoing basis mainly for ensuring the functioning of the interoperable ICT as anticipated, such as the procedures that should be followed when working with the model, specific families of objects that should be turned on/off, and so on. These technology-centred discussions were not only focused on the design stage, but also considered the use of models in construction and operation stages.

In this regard, CDMCMs mainly dealt with bridging between models (i.e. model-based work) and the developing design and construction on the site. This involved a variety of discussions which aimed to pragmatically reconcile various technological aspects of model-based working (i.e. capabilities and rules) and the changing circumstances of developing design and site works. This process was not always a smooth one and tensions among various stakeholders occasionally arose. Two discussions of this sort happened during two different CDMCMs. These are presented below as events (EE 5 and EE 6).

Project EduBuild- Event 5 (EE 5) shows how model-based working did not automatically satisfy or facilitate the coordination requirements of the architect and M&E sub-contractor, as (shared) model-based working could not equally accommodate their diverse needs. As a result, an interdisciplinary discussion was needed to reconcile the workflows and priorities of the architect and the M&E sub-contractor considering the capabilities and rules of the technology; and therefore, to enable interdisciplinary model-based working.

Project EduBuild - Event 5 (EE 5) – M&E models lagging behind

> *In one of the CDMCMs, the representative of the architect stated that the architectural team needed the light fittings and fixtures modelled in the M&E model for the coordination of the suspended ceiling design. The modelling manager of the M&E sub-contractor stated that the M&E modelling team had taken the decision to model them last. The design manager of the main contractor supported the architect, and stated that they had agreed that the M&E sub-contractor would model the light fittings and fixtures at that stage of the project. The modelling manager of the M&E sub-contractor argued that they previously put considerable effort into modelling the light fittings and fixtures at the atrium area, and then, when the hosting objects were deleted in the architectural model, their whole effort was wasted. He continued by saying that, therefore, the M&E modelling team decided to model the light fittings and fixtures last, when the coordination of and decisions about them would be completed. He argued that the coordination had previously been done by overlaying 2D drawings on the architectural model and this could be done like this again. The architect and the design manager objected to this argument. The representative of the M&E sub-contractor, who was annoyed,*

explained that the modelling platform (MP) that was imposed by the client was not geared up for M&E services, and they had already needed to create half of the objects including switches, plug sockets etc. from scratch. He continued that they had modelled all the equipment in other software where it was much easier to model, but exporting it to the MP was problematic. He further argued that his colleagues on the site who were responsible for the installations asked for the systems to be modelled as closed systems with all the elements connected to each other in the information models in order to make sure that the system calculations and design were adequate and finalised. He added that the MP took almost a minute after each single change when working with connected and closed systems as the computer needed to re-calculate the whole system again, and this made the MP even harder to use efficiently. Moreover, he argued that, in the MP, automated connections between different elements of the system could be wrong unintentionally. Although the design manager of the main contractor added that other design disciplines did not need a closed M&E system, and just the geometry was enough for their coordination purposes, this was in contrast with the general expectation that MP should be used as a full design development tool. At the conclusion of the discussion, the modelling manager of the M&E sub-contractor calmly told the architect that his modelling team could not provide all the required items in the model in such a short time; but, they could adjust their modelling priorities to the needs of the other stakeholders.

Later in the project, when the ceilings were being installed on the site, the suspended ceilings needed to be re-documented in several 2D drawings with a much finer level of detail and with actual measurements from the site because the installation tolerances on the site made the modelled setting-out details irrelevant.

Clash-detection exercises constituted another example of the continuous need for pragmatic reconciliation of various technological aspects of model-based working and the changing circumstances of developing design and construction on the site. Clash-detection exercises required bridging the gap between the practice of *modelling* and the practices of *design and construction* by way of discussions that were held during the CDMCMs. Although 'clash detection' was a promoted technological feature of the adopted shared BIM platform, in the observed meetings, clash-detection was not a completely automated exercise but mainly achieved through discussions. Clash-detection tolerances and rules were negotiated, and also thousands of clashes were filtered by practitioners through discussions in order to find out which of the detected clashes were relevant for design development, particularly in consideration of i) the stage of the design; ii) the potential impact of the clash on the site; and iii) the modelling approach adopted by the modeller. The following event (EE 6) shows how the discursive exercise of clash detection caused tensions at times due to the conflicting pragmatisms of modelling, designing and constructing.

Project EduBuild - Event 6 (EE 6) – In-discipline clashes and what is the purpose of clash detection?

In the EduBuild project, there was a constant struggle to benefit from automated clash-detection. The main challenge was to handle thousands of clashes detected by the BIM software to differentiate between the clashes that resulted from real design problems and the ones that resulted from non-detailed modelling. Due to time constraints, the main strategy for handling this was to filter the list of clashes according to 'object families', and strategically choosing the families that were more likely to clash because of real-design problems. For example, everyone in the project would know that structural columns would be in their place well before the application of screed on slabs, and therefore, the clashes between these two were marked as 'approved' when they were detected by the software. Marking clashes as 'approved' enabled the practitioners to neglect these clashes in future clash-detection exercises. Consequently, in this context, the ideal of a clash-free model did not mean a model without clashes but rather it meant a model with managed clashes. Such a strategy required strictly following naming conventions in models and also setting up some additional clash-detection rules in the software. However, defining too many additional rules was not found beneficial as with each new rule there was an exponential increase in the number of clashes detected. Another implicit strategy to handle the huge number of clashes was to look for unusually large or low numbers of detected clashes under the filtered families. In such cases, first the underlying technological causes were questioned (e.g. turned on/off clash-detection rules, versions of the uploaded information models etc.) followed by more-detailed discursive investigations about the detected clashes.

The overwhelming number of detected clashes and uncertainty about the underlying reasons caused tensions during clash-detection exercises. On the one hand, the criticisms of the representative of the client and the design manager of the main contractor about the high numbers of clashes were not well received by the designers who were supposed to both develop the design in an iterative way and model the *information in clash-managed ways. On the other hand, although the client representative and the design manager of the main contractor were insistent on keeping the models clash-managed, they were aware about the potential shortcomings of using the automated clash-detection alone in assuring a clash-free construction. They repeatedly warned the designers that delivering clash-managed models did not remove the designers' responsibility for delivering a design that can be built without any clashes. They suggested that the designers also consider their traditional design coordination measures to ensure this.*

In the meeting where this event happened, the architect was criticised for having too many in-discipline clashes between the furniture and internal wall families, which were both 'owned' by the architect. The unexpectedly high number of clashes created a sense of disturbance in the team. The architect claimed that he was aware of these clashes and these did not need to be picked up at that moment because the locations of most of the furniture were not finalised and therefore the architects did not seek to model them clash-free. The design manager of the main contractor further criticised him saying that, he should not have had exported the unfinished worksets for clash detection. The architect objected to this by saying that although clashes between furniture and internal walls were not relevant at that stage; they needed to check for the clashes between some of the fixed furniture with other disciplines' designs. The architect, who was upset, further stated that if on the site there was an in-discipline clash due to architectural modelling, they would be ready to pay for the extra cost. He then started to question the purposes of model-based design. He criticised the critiques regarding architectural in-discipline clashes which he thought were normal at that stage of the design. As an answer to the architect's statement, the design manager of the main contractor stated that models were not only discipline-specific design documents but shared mediums which would also be used for construction and operations; and therefore, the targets and procedures in place needed to be followed to satisfy multiple requirements from models.

In Table 6 below a non-exhaustive list of different types of discussions that were observed during CDMCMs is provided. The evidence included in Table 6 shows what kind of discussions that the practitioners needed to have on an ongoing basis to handle the implications of the interrelated needs of model-based working, design development, construction works, and the operations and maintenance phase of the building. The time lag between the first and last observed CDMCM was around eight months.

CDMCM No	Topic of discussion	Summary of discussion
1	Abundance of detected clashes in architectural model (see Event EE 6)	The number of clashes found in the architectural model was criticised by the design manager of the main contractor and the representative of the client. They claimed that unfinished parts of design must not be published to avoid in-discipline clashes. The representative of the architect claimed that, although unfinished, they needed to export the 'workset' with the furniture to check some of the fixed furniture with models of other disciplines. Moreover, the representative of the architect claimed that if there would be in-discipline clashes on the site then they would take the responsibility for it. However, he was opposed by the representatives of the client and main contractor who claimed that the model was not only for construction but also for operations and maintenance.
1	Allowed tolerance of clash detection	The discussion was about the tolerance defined in the software to neglect certain clashes. It was stated that for this meeting the tolerance was set to 100mm and it would be gradually decreased over the following clash detection exercises.
1	Follow-up of the identified clashes	How the correction of the identified clashes will be followed-up by various stakeholders was discussed.
1	Upgrade to a newer version of the software	It was announced by the representative of the client that the software would be upgraded to 2014 version. A discussion was held to identify how a smooth transition process can be assured. For example, practitioners agreed that the major identified issues in the models must be sorted before the upgrade, and the various links among stakeholders' models should be turned-off before upgrading.
1	Clash free model and clash free design (see Event EE 6)	The high total number of the detected clashes triggered an ongoing discussion around which of the clashes are negligible and which ones were important. The representative of the client stated that the site works can clash by the time clash-free model would be established. He stated that it was the fundamental role of the members of the design team to assure a clash-free design and therefore they must take all the necessary precautions in addition to clash detection exercises to assure that there would be no clashes on the site.

1	Preparing models by different design disciplines for clash detection (see Event EE 6)	The high number of clashes also triggered a discussion about what worksets must not be exported and what objects must be turned-off etc.
2	Follow-up of the identified clashes	The procedure changed from creating a list of clashes that needed to be corrected to working with the merged models one after other. If any of the consultants thought that a clash assigned to their name was not related to them, they would create a 'review' request.
2	Coordination of the elements of design that were not in models	A discussion about what were the things stayed out of modelling (e.g. brackets of curtain wall) and might require coordination? How they would be coordinated? Whose responsibility was to coordinate them?
2	Discussions regarding the automatically detected clashes that were decided to be checked after the initial filtering	Discussions on whether the clashes were relevant (i.e. whether any action needed to be taken). Design-related discussions were held when clashes were assessed to be relevant for design development or construction works.
2	Model development requests for future coordination and clash detection (see Event EE 5)	The representatives of the architect asked the M&E modelling manager to model the lighting fittings and fixtures in order to coordinate and clash-detect the ceilings. However, the modelling manager of the M&E sub-contractor stated that they were planning to model them last, once the ceiling design of the architect finished. The discussion became an argument. At the end, the parties agreed on prioritising the parts required by the architect in the model.
2	Expectancies of the site personnel from the model (see Event EE 5)	The representative of the M&E sub-contractor explained how the site team expected fully modelled and calculated M&E systems to assure that they would not face any problem during the installation. He stated how this was difficult to do using the shared modelling platform due to its particular way of operating.
2	Laser scanning of the ground floor	Discussion on how the results of the laser scanning would/could be used? (e.g. for clash detection or just visual inspection?)
3	Unexpectedly too many clashes with drainage model	Too many clashes with drainage model, which were not there before, were detected. There were new clashes detected even at the places which were not changed at all. The practitioners tried to find out what might have caused this: Was the drainage model at the right place? (Was it linked correctly?) A point of reference was tried to be found to validate the positions of the objects in the drainage model but this was unsuccessful. They decided to check it after the meeting.

3	Unexpected kinds of clashes	Clashes between the landscaping model and other disciplines' objects were detected. It was questioned whether the leaves of the modelled trees could cause clashes.
3	Introducing a new software and Asset Information Matrix (AIM)	The representative of the client announced that they would like to introduce a plug-in for the modelling software which was designed to connect the design model to site works. The main purpose was to automatically create the maintenance model by capturing the installations through the plug-in to avoid re-work. The client team prepared an Asset Information Matrix (AIM) which detailed what parameters needed to be included for each object in the maintenance model.
3	Operation and Maintenance (O&M) manuals	The representative of the client explained how O&M manuals would be attached to the model, and how they would be named and grouped under various folders.
4	Producing as-built models	The following issues were discussed in consideration of producing the as-built models which would be handed to the client at the end of the construction: the inconsistencies between the modelled design and site installations, the level of detail required for the as-built models, and the allowed tolerances for the as-built models. There has also been a discussion about whether the additional work for turning design models into as-built models were mentioned in the contracts of the designers. Sub-contractor (e.g. steel works) models has been a further topic of discussion, as it was not clear to design consultants whose responsibility was to update sub-contractor models while producing as-built models.
4	The procedure of updating the existing models to as-built models	The coordination needs for updating various existing models to as-built models were discussed. This was important because if one stakeholder changed something in one model this could have knock-on effects on many different aspects in the other modelled parts. The participants of the meeting decided to take their time and talk with each other before making any changes to the existing models for synchronising them with the as-built situation on the site.

4	Documentation for the operations and maintenance	The software plug-in that was introduced to connect the design model to site works enabled the collection of some of the Operation and Maintenance Manuals (O&M) at the time of installation on the site. However, the members of the design team also had already uploaded some O&M on the online document management system. There were overlaps between these which meant that there were two sets of O&M for some of the installed systems. A discussion was held to agree on an arrangement for consistently providing O&M.
4	Snags	There were two types of snags. Model snags: the things that needed to be corrected in the model, and site snags: the things that needed to be corrected on the site. A discussion was held to set different procedures for these two which revealed that model snags and site snags could be different.
4	Distinction between Request for Information and snagging	There was a confusion about the use of the new software plug-in which enabled producing snag lists that were digitally assigned to specific design practitioners. Design practitioners were uncomfortable about being digitally assigned snags in a shared medium while there were no real snags but just lack of information. Therefore, what could be assigned as a snag and what would rather be identified as a Request for Information were discussed. These two would imply and require different things for different people, and therefore it was important to differentiate between them.
4	Distinction between snagging in the finished rooms and snagging in the rooms under-construction	There was a difference between unfinished work and deficient work; and the two situations would require different actions. A discussion was held about how these could be communicated and/or managed in the software plug-in introduced to connect design models with the site works.

Table 6 - A non-exhaustive list of the discussions observed during the CDMCMs of the EduBuild Project

6.2.3. Model-based working as part of the wider organisation (zoom-out x2)

The previous section has showed that in the EduBuild project, model-based working and design development diverged in their needs, and required separate vocabularies, roles and meetings to be handled. This section 'zooms-out' to the level of interrelated practices to further explore the causes of this divergence as well as how it is experienced in the wider organisation of the project. Therefore, this section presents both an account of in-discipline modelling practices to better expose the causes, and an account of how this divergence is experienced in wider organisation of the design work. Zooming-out to the level of interrelated practices reveals that in-discipline modelling practices were dominated by technological considerations because it was essential to 'appreciate and agree on a BIM way of working', which was structured (i.e. scripted) and technology- (i.e. data-) driven, in order to keep the modelling software up and running to deliver the expected benefits. However, there were inadequacies in this that required pragmatic adjustments to the 'BIM way of working' (see Section 6.2.3.1). On the other hand, findings about the wider organisation of the design project reveal that the modelling practices and other interdisciplinary activities had to be mutually adjusted in consideration with 'contractual requirements', 'level of development of design and changing needs of various stakeholders', and 'dynamic and iterative design workflow' (see Section 6.2.3.2).

6.2.3.1. Modelling practices

The formal and informal communications with the members of the design team revealed that modelling practices required a structured and controlled approach that acknowledged the particular ways that BIM technologies operated. In the following, findings about the hands-on, in-discipline modelling approaches as well as the challenges with modelling through the rigid structures of the BIM technologies are presented.

<u>Appreciating and agreeing on a BIM way of working</u>

The findings suggest that there was a strong commitment to the standardisation of the way models were created, particularly through using naming conventions, setting separate 'worksets' for each discipline, and having agreements on models' contents. This allowed different parties to interrogate various discipline-specific models for their own design-development purposes, and also for managing clashes. These conventions were partly articulated in the BIM Protocol (e.g. naming conventions). It was acknowledged by all the parties that creating and following a consistent structure for 'object' development was the key to benefiting from the linked models and to produce the healthy development of design in BIM environment. However, this alone was not sufficient due to the complexity of both modelling and design development such that regular on-going discussions were needed to keep models consistent for all the parties as presented in the previous section.

Interviews revealed that the design team stuck to in-built tools provided by the shared modelling platform as much as possible, to avoid the potential problems that might occur because of stepping outside the structured BIM way of working. Therefore, for example, generic objects were created only when existing tools were not able to satisfy the design purposes at particular instances. For instance, although the architects created an object family for furniture, they chose to model fitted furniture under the 'generic model category'. The reason for this was that they wanted the fitted furniture (e.g. reception desk) to be always visible in the digital model even when they turned off the loose furniture data layer. It took considerable discussion to decide what to include and what not to include under the 'generic model category' but a consensus was achieved and fewer conversations were required after this. Consequently, the modelling software has an embedded logic and understanding this logic was important in order to document the design correctly.

In a similar way, the modelling software allowed the creation of extensive connections between objects and the opportunity to assign many attributes to the objects. However, this required dealing with similar objects with consistency and planning in advance in order to know how these attributes would be used. For example, if rooms were defined as spaces by the architects, the mechanical engineers could use the model to conduct ventilation analyses. Similarly, most of the objects could be scheduled automatically (e.g. schedule of doors, windows) if defined consistently in the model. However, relying on these automated functions brought its own risks because if there was a problem, it became particularly difficult to find where it was generated from. Additionally, the designers needed to understand the ways that measurements were performed by the software to ensure that what was scheduled was actually what was designed. Curtain walls, for instance, were problematic in this sense. The in-built 'curtain wall tool' of the software, took it to be an opening in the wall, however curtain walls' fixing elements spanned beyond the visible opening in the model, thus causing potential misunderstandings about the size of the curtain wall in schedules.

A useful feature for designers in the modelling software was that objects were created once, and then developed over time. This made it necessary to assign 'ownership' to each object to ensure that they were adequately handled during the design development. Ownership of digital objects in models required significant coordination, because objects were used by other members of the team. Similarly, in the modelling software, different members required different views of the model, and each design discipline needed to decide from which plane they had to cut the model to obtain the view most useful for their purposes. Although there had been the flexibility to create almost any views, the fact that not everything was detailed in the model meant that extra time was required to enrich the views with annotations.

Pragmatic adjustments to BIM way of working

The outlined BIM way of working was determined by the functionalities of the BIM software, however the software did not work universally, and so pragmatic adjustments were needed. For example, the auto-joint feature of the software did not satisfy the architects in some instances such as at some column-curtain wall joints. In these instances, the auto-joint feature extended the wall layers onto the column, which was not the design intent. After long discussions, the architects decided to black-out these joints to force people on the site to refer to 2D drawings where they could correctly document the joint.

In a similar way, the functionalities of the software were used pragmatically. For example, the architects did not want to connect the walls to the slabs, because slab objects were 'owned' by (i.e. were the responsibility of) the structural engineer. They wanted to be able to turn off the structural elements and still have the walls visible. Although they acknowledged that this was against the logic of parametric design, based on the fact that they fixed the heights of the levels quite early in the design, they did not think the parametric feature was of value considering the limitations it brings. Furthermore, they created red 3D marker objects visible in all views to identify important coordination issues. As these markers were objects in the model, they also could schedule them to see all the pending coordination issues. Similarly, they created placeholder objects to specify objects that they did not 'own' but that they needed to coordinate their own designs. These placeholder objects were simple representations of the real object and were replaced by fully designed ones when the real owner of the object developed the design to the point that this object was needed. For example, radiators were first created as placeholders (i.e. as empty boxes) by the architect to coordinate the room layout, but later replaced by the actually intended radiator objects by the M&E sub-contractor.

6.2.3.2. Working with the model

Zooming-out to the level of interrelated practices also revealed that the divergent needs of model development had impacts on other interdisciplinary efforts of design development, and therefore had to be actively dealt with during design development. In the following, an account of how this divergence was experienced and handled in the EduBuild project is presented.

Contractual issues

Contracts were important determinants for how the design was documented. On the one hand, the considerations about contractual issues were significant for practitioners in determining how the design would be documented to satisfy professional reliabilities. In the EduBuild project, the same views and drawings as pre-BIM practice were still created because the contractual documents in the background were based on 2D drawings. Therefore, as stated by the interviewees, it was "*still mainly based on 2D drawings but coordinated through 3D*". There was a general disclaimer on the published models which said that any information that existed in the model but not in 2D drawings should be checked with the owner of the object. This was because, as stated by an architect, there were "*things that just don't work with a BIM way of working*". Similarly, it was explained in the interviews that the model as a design output could cause arguments between designers and clients. More specifically, although the scope and content of the model could be specified, it was impossible to specify every single detail about modelling and the client might end up arguing that the model was not developed appropriately. Therefore, in this situation, 2D drawings were perceived helpful in ensuring that the design was useful, workable and satisfactory for various needs and expectations.

On the other hand, modelling-related liabilities detailed in the contract and BIM protocol obliged the members of the design team to be in close contact with each other and the client team to develop fully coordinated design-, construction- and maintenance-models that satisfied various needs of each stakeholder and each stage of the project. This meant that, the members of the design team were limited in taking individual decisions about their own modelling scope and content, because the model was specified as a deliverable of the contracted design services, rather than just being a tool to deliver other specified design outputs such as drawings and schedules.

<u>Aligning the evolving needs of various stakeholders with BIM way of working</u>

The level of development of design determined the information needs of various stakeholders. Satisfying these needs while committing to the 'BIM way of working' was an ongoing consideration for the practitioners. Such considerations revealed themselves in different ways at different stages of the design; and they were dealt with through ongoing interdisciplinary interactions (i.e. in DCMs, in CDMCMs, and through remote interactions as described in detail in Section 6.2.2).

According to the findings of the interviews, at the early stages of the EduBuild project, the modelling software did not satisfy the needs of the practitioners, so the practitioners developed the initial conceptual design using sketching software, and 2D drawings. The information models were created at RIBA Stage C. During RIBA Stages C and D, mainly generic objects were used in the model. It is only at RIBA Stages E and F that these generic objects were largely swapped out with the objects from the 'object families' that were built in the software. This allowed the model to be flexible at initial stages of design so that it could be changed quickly during early stages of design development. For example, at Stage C, the design team wanted to see only that there was a door in a particular place, but they were not interested in any particular property of that door apart from its location and approximate size.

Active management of the level of detail in the models (i.e. and in the design artefacts issued from them) was an also an ongoing consideration during the detailed design stage (i.e. RIBA Stages E and F) of the EduBuild project. An example of this was the need to use placeholder objects as explained in the previous sub-section. Furthermore, for the detailed design stage, a decision was taken about not to model anything more detailed than at 1/50 scale, and to utilise linked 2D detailed drawings instead. However, some objects that were assessed to be insignificant for design checks (e.g. brackets, brick supports, seals etc.) were decided not to be modelled at all (i.e. even if they were larger than 1/50) but only shown in 2D detailed drawings. This 'in-model' vs. 'out-of-model' documentation of design became a source of interdisciplinary discussions to clarify what were left out of the models and how they would be coordinated.

Another issue about the level of detail of models appeared in clash-detection exercises. In many instances, for the sake of efficient use of time, objects were deliberately left clashed with each other because the extra effort to develop a clash-free model at a given stage of design was assessed as being unnecessary. For example, the screed was left to clash with structural columns during the design development because everyone knew that, in reality, the screed would run up only to the columns (see Event EE 6). Therefore, this would not cause any problem on the site and did not deserve more modelling effort. Another explanation given for this was that the clashes resulting from deliberate non-detailed modelling did not appear in most of the model views, especially if the visibility settings of the model was set to medium or coarse level of detail. However, these 'deliberate' clashes were still detected during clash-detection exercises and needed to be managed by practitioners in order to differentiate between relevant and irrelevant clashes (see Event EE 6). On the other hand, as stated previously, although there were deliberate modelling decisions that did not reflect the reality, all the construction details were correctly included in the generated 2D detailed drawings and the annotations added on them. Consequently, maintaining a balance between the usefulness of clash-detection exercises (i.e. model-based design control), modelling effort spent on various elements of design, and non-modelled artefacts, was an ongoing consideration. Events EE 5 and EE 6 (see Chapter 4) show examples of how this balance was effortfully maintained through interdisciplinary discussions.

Furthermore, it was also observed that the levels of detail in models were continuously assessed through interdisciplinary discussions to establish what kind of design checks could be performed in, or through, the models. For example, towards the end of the observation period of the EduBuild project, it was decided to move away from clash detection exercises to virtual walk-around exercises in CDMCMs. The previous experience of the design team in the Phase 1 project suggested that there might be problems with modelling and/or design that might not captured by clash-detection exercises, such as electric switches hanging in the middle of a room but not clashing with any other objects. Such modelling issues could hide bigger design clashes by not being modelled correctly. Interdisciplinary discussions were required about such issues (i.e. similar to the discussions that were held to assess the relevance of the detected clashes for design, construction and maintenance) in order to establish their relevance for the project. Consequently, maintaining an adequate understanding of the level of detail and precision in models was an ongoing consideration in judging for which purposes the model could be used, and to what extent.

The level of detail was also important in creating appropriate ‘coordination views’ in models. There was an ongoing discussion regarding this issue between the different disciplines that shared models with each other; as each wanted to see certain aspects of design models and not see others, based upon their discipline-specific focus. It was stated by all the interviewees that when a model was received from another discipline, it was very confusing to have it in the level of detail that the sender used. Therefore, agreements on what and how they wanted to see a certain view were considerations that needed to be dealt with.

<u>Aligning the model-based working with dynamic and iterative design workflow</u>

It was observed that the designers needed the design information stored in the models to develop their own design. Therefore, the design workflow was connected to the model development. Individual disciplines used other disciplines' models as input to develop their own models and designs. When there was a problem with the synchronization of the model development between parties, 2D CAD drawings of other disciplines were used to coordinate in-discipline design.

It was observed that it was impossible for individuals to make decisions by looking only at the model, because of the iterative and ever-developing nature of the design. Therefore, conversations were vital no matter how good the models were. These conversations were combined with 2D drawings which were complementary to the model. 2D drawings with their annotations and revision numbers told an invaluable story and retained the thrust of the design intent. Due to the ever-developing nature of design, the model was always incomplete in different ways for different disciplines. At any point in time, the model was only "*a snapshot of work in progress*" (a representative of the architect) and the designers did not know what the final design would be. The iterative nature of design required jumping back and forth through different iterations. This caused problems in model-based design communication. In the Phase 1 project, for example, an electric switch owned by the M&E sub-contractor was orphaned when an architect deleted a wall, which required communication outside of the model environment.

6.3. Interdisciplinary Model-based Working in the OffiBuild Project

6.3.1. An overview of the project-specific context of model-based working (zoom-out x1)

The OffiBuild project was significantly different than the EduBuild project in terms of interdisciplinary model-based working. In the OffiBuild project, there were no contractual mandates or formal agreements regarding the use of Building Information Modelling. Indeed, during the observation period, the main contractor did not have any signed contracts with any of the design consultants, and developing the design to Construction Proposal level had been one of the design milestones around which the design was organised. Nevertheless, the architect adopted a model-based design approach as the representatives of the architect believed it was good practice. They took this decision after negotiating with the structural engineering consultant who agreed on the principles of model-based working. Consequently, although there was no detailed documentation (e.g. BIM protocol, Employer's Information Requirements etc.), strategies or plans for model-based working, models were used by the architect and the structural engineering consultant in developing the design. Other stakeholders of the design team, such as the main contractor and the M&E consultant, had access to the model but did not interact with it during the observation period. More specifically, they occasionally visited the model to check the design or develop insights about the design as documented in the model, but they did not contribute to the model. Instead they worked with the design artefacts issued through the model. In the following sections (i.e. Sections 6.3.2 and 6.3.3), first the orientation of interdisciplinary interactions related to model-based working are presented (i.e. zoom-in), followed by a further zoom-out to the level of interrelated practices to establish a connection between the observed interdisciplinary interactions and the wider organisation of the project.

6.3.2. Orientation of the interdisciplinary interactions concerned with model-based working (zoom-in)

In this section, interdisciplinary interactions concerned with model-based working in the OffiBuild project are presented through a chronological order which exposes the gradual change in their orientation. In the OffiBuild project, during the observation period, the main mode of interaction regarding model-based working was face-to-face interactions during DCMs. At the early stages of the observation period, the information model was hardly referred to or used during DCMs but another 3D sketching model was mostly projected on a large projection-screen, and actively used during the system-level exploratory discussions (e.g. curtain wall, roof type, façade types etc.). At that stage, an architectural information model (i.e. building information model) was uploaded on the online document management system and was accessible to other members of the design team, but it was hardly referred or shown in DCMs.

During this period, only the architect developed and modified the 3D sketching model (using a separate 3D sketching software), and the other members of the design team did not have direct access to the 3D sketching model. Therefore, the 3D sketching model was not an interdisciplinary medium. However, other members of the design team (e.g. the structural engineering consultant, the M&E consultant) had access to the architectural information model, which was uploaded to the online document management system, and used both the information model and the design artefacts (e.g. floor plans) issued through it, in order to develop and discuss their initial designs in DCMs. They brought printed design artefacts to DCMs to present their initial design, and engaged in interdisciplinary design development discussions with the visual help provided by the projected 3D sketching model.

At the time, there was one model (i.e architectural information model) and a set of design artefacts issued through it, and therefore there were not many discussions regarding the coordination of different models or design artefacts. Moreover, the initial design did not require close coordination of various discipline-specific designs, therefore the researcher did not observe any model-related interdisciplinary discussions during the first month of the observation period. Although the presence of an information model was mentioned sometimes in DCMs during this period, the information model did not appear in DCMs and was only mentioned by the architect in terms of what was in the model and what was being developed and would soon be issued as design artefacts (e.g. updated floor plans, elevations etc.) for the use of others. It was known that the rendering capabilities of information modelling software was better; however, the 3D sketching model was preferred at early stages of the observation period because of its better capability of experimentation, which mattered more than rendering quality at that time.

After a month from the beginning of the observation period, the level of detail in the architectural information model started to be occasionally needed during discussions and therefore the architectural model was started to be shown in DCMs in addition to the3D sketching model. The representative of the architect usually created pre-set views on the 3D sketching model to express his points and showed previously-agreed system-level design decisions. Also, real-time changes were made on the 3D sketching model, such as changing the type of the windows. However, occasionally the architectural model was also used especially when the content of the 3D sketching model was insufficient to assist the discussions. Generally, when the topic of discussion was concerned with the inside of the building, 2D drawings were preferred rather than 3D models. When there was a challenging part of the design (e.g. the meeting core), sometimes the architectural model was used to view a cut section (i.e. a 'slice' of the design) to better understand the implications of the discussed architectural systems.

Increased references to, and use of, the architectural model in DCMs also raised more questions about, what was in the model, how close the model was to reality (i.e. both in terms of ratios of the shown elements of the building and consideration of the design decisions taken so far), what design propositions were incorporated in the model shown in the meeting, and so on. These conversations also led the main contractor to ask the architect to add specific details to the model, which triggered discussions that revealed the particularities of model-based working. For example, the bid manager of the main contractor once asked the architect to incorporate the laser-scan-survey results of both the existing building and the construction site in the architectural model to generate more precise elevation views with the correct coordinates. He stated that both the existing building and the construction site were laser surveyed, albeit separately, and therefore linking those surveys to the architectural model would be easy. The architect in the room claimed that it was not that easy, and to turn the content of laser surveys to model objects required time and effort. Another similar example happened when the architect was asked to change some parts of the façade of the building upon the informal feedback of the people from the planning department of the city council. The representative of the main contractor believed that the floor plans would not need to be revised but the architect said that everything connected to each other in the model and therefore all the floor plans would need be re-issued and this would have cost implications for the main contractor.

The increasing number of the design artefacts and decisions that concerned various disciplines raised the need for discussions about the coordination of various design artefacts, thus, gradually shaping what would be coordinated through the model and what would be coordinated outside of it. The general approach of the representative of the main contractor at that time of the observation period (i.e. the second month – middle of RIBA Stage D) was to coordinate the design through design artefacts and leave the responsibility of model-based working to the architect and the structural engineer. More specifically, the bid manager of the architect was not concerned with the status of the model inasmuch as it satisfied the production of the specified design artefacts required by the envisaged design milestones. Therefore, the design had been developed according to various design artefacts which were not necessarily produced in coordination with the model. In other words, the model was not the originator of all other design documents, but was linked with various design artefacts on an ad-hoc basis when it was thought necessary. For example, to select the furniture, the bid manager of the main contractor asked the architect to cross reference the floor plans from the model with client's FF&E schedule. Then the furniture could be selected and priced to see if the budget was satisfied. As a result, the design having been developed through loosely coordinated artefacts and modelling, sometimes left the members of the design team in a difficult position to progress with their design. This also happened in Event OE 2 (see Section 4.3.3.1). In this instance, unintegrated survey results and the architectural model obliged the M&E engineers to develop a rudimentary solution for external lighting rather than a more-complete design that could be used as the basis of the external lighting in the future.

Although either 3D sketching models (i.e. from the sketching software) or architectural information models were often projected on the large projection-screen in the meeting room, practitioners switched between 3D models, printed design artefacts, schedules and Room Data Sheets according to changing topics of discussions. For example, when FF&E was being discussed, Room Data Sheets were used rather than the model. When BREEAM points were discussed, a list of potential BREEAM credits were used. At times, the 3D model, 2D drawings, schedules, and Room Data Sheets were employed in combination when implications of a given potential building system were explored from multiple perspectives in DCMs. At the time, the structural model was still not issued and was being developed, based on the architectural model. Therefore, the structural engineer mainly informed other members of the design team about the ongoing structural design through the printed design artefacts that he brought to DCMs. He also mentioned that there was a modeller in their office who was dealing with the modelling of the structural design in the shared modelling-platform, and he was mainly dealing with developing the design rather than modelling it. Once, when the researcher asked the structural engineer whether the drawings he brought to the meeting were issued through the structural model, he answered "*that is what they said*".

In the third month of the observation period, after the first submission of the planning application, it was decided that it was timely for issuing the structural model in order to complete the RIBA Stage D-level design in a coordinated way as was asked by the project manager (PM) who represented the client (client PM). It was decided that the coordination between the architectural and structural models would be easier if the two models were always kept linked, and only one design consultant worked on the linked models at a time. According to this arrangement, the structural engineering consultant would have a separate structural model through which it could separately develop the detailed structural design. However, in terms of interdisciplinary design coordination, it was decided to have one shared model that would be accessible by the design team; and this shared model would consist of a filtered version of the separate structural model linked to the architectural model. Therefore, in this arrangement, the architectural and structural designs and models were supposed to be developed through the following cycle: the structural engineering consultancy takes the shared model published by the architect, uses it to update the detailed structural design in the separately held structural model, amend the structural model in the shared model accordingly, and send the updated shared model back to the architect, architect updates the architectural design in the shared model, and then publishes an updated version of the shared model which would be used by the structural engineers in their next cycle of coordination. The aim was to have only one shared model at all times in the online document management system, and assign one design actor to be ultimately responsible for the shared model: the architect. The decision of having one valid model for the shared use of the design team at all times, was also part of assuring the consistency among separately-developed design artefacts. More specifically, after this decision, the design manager of the main contractor stated that the interdisciplinary check would be based on the model that would be stored in the online document management system. In other words, he asked all stakeholders to coordinate their design-development activities with that model.

After this decision, model-related discussions were initiated between the representatives of the architect and the structural engineering consultant in DCMs. For example, the structural engineering consultant stated that reinforcement-bars would not be included in the shared model. Also, as soon as the first week after this decision, the representative of the structural engineer stated that they would still need the design artefacts issued from the model by the architect to develop their design and only handing the model would not be sufficient. The representatives of the architect agreed with this but they claimed that the structural engineers should first check the critical aspects of the architectural design in the model (e.g. heights, slab thicknesses etc.) before the issue of further design artefacts through the model to avoid re-work as much as possible.

At about the same time of the observation period, the representative of the architect introduced a colleague to the design team to be the main person responsible for modelling. After being assigned as the ultimate responsible of the shared model and with the addition of the new colleague, the architectural team began to be asked to do more and more additions to, or amendments in the model by various stakeholders. For example, the structural engineer was repetitively stating that they were waiting for the architectural model to be updated to proceed with their detailed design, and the quantity surveyor of the main contractor was continuously asking for various plans, sections and specifications for market testing. This responsibility assigned to the architectural team sometimes implied that the architects were reluctant to do detailed modelling of the highly contested areas of the design such as roof and the meeting core. In one of the DCMs during the RIBA Stage E, at the fourth month of the observation period, the representative of the architect openly stated that, they did not want to spend too much modelling effort for the roof, and only then to be told that what they designed was too expensive or inappropriate.

Architectural model-development and structural engineering model-development followed different processes in this interdisciplinary model-based working arrangement. The structural engineers coordinated their separate structural model with the developing architectural design at distinct rounds. At each round, they used the architectural design in a version of the shared model to update their separate structural engineering model. After updating their separate model, they then issued design artefacts that showed their updates to the structural design. These updates were first discussed and iterated in DCMs through these design artefacts. Once decisions were agreed upon, then the structural engineers finalised their separate model, and re-issued the design artefacts. Only following the completion of these steps that would they finally populated the filtered structural model linked to the architectural model (i.e. in the shared model), and sent an updated version of the shared model back to the architects. On the other hand, the architects were expected to reflect all the discussed amendments to the shared model as soon as possible (i.e. not at distinct intermittent rounds), even if they were structural amendments (e.g. when the sizes of structural columns were decided to be amended, the architect was expected to make the necessary changes without waiting for the next structural engineering update to the shared model). Although the architectural design was work-in-progress like any other discipline-specific design, the other members of the design team expected the architects to continuously re-publish updated versions of the shared model based on the developing design. This was due to the model-based working arrangement in place, which almost equated the architectural model to the shared the model. Also, as a result, updates to the shared model were largely based on discussions that were held using printed design artefacts. The results of these discussions were reflected in the model mainly by the architect, but the structural engineer also checked and updated the shared model at times. In other words, the model was managed mainly by the architect, and was contributed to, and checked by, the structural engineers at times. For example, it was clearly stated by the design manager of the main contractor that the architect was responsible for any potential clashes between the architectural and structural designs.

Once the structural frame and external wall thicknesses were fixed, the characteristics of the model coordination between the structural engineers and architects changed. As stated by the senior structural engineer: "*Floor plans are fine but the important things are the interfaces. So what is happening when you come to a corner for example?*". At this stage of the project, discussions regarding the level of detail that needed to be included in the shared model started. These discussions involved whether everything would be modelled to the level of detail required by the construction team, or whether the model would be complemented by other more-detailed design artefacts such as 2D detailed drawings. The modeller architect generally claimed that he could model everything to the required level of detail. For example, when the design manager of the main contractor asked "*are we going to have some other detailed drawings which are not in the model to show some details like the copper at the end of the sills etc*.", the modeller architect claimed that he could model and annotate them. On the other hand, the senior architect generally claimed that the main point would be to provide a set of documents that allowed building and measuring, and in this regard 2D drawings would complement the model.

The increasing level of detail of both architectural and structural designs increased the number of conversations among the architects and senior structural engineer regarding what was in the model, who was doing what in the model, and whose responsibility was to review what. At the same time, questions about whether a particular design artefact was uploaded in the online document management system, or reviewed, and so on, were started to be asked frequently. A large amount of time in DCMs was being spent on reviewing the issued drawings by the architect or structural engineering consultant. Design discussions were held mainly through the issued design artefacts, and the model-related discussions were about the coordination of the shared model rather than anything related to design issues. At that time of the design, the increasing level of detail in the model together with an increasing number of conversations about coordination of the model between the architects and senior structural engineer started to worry the design manager of the main contractor. He started to state more forcefully that the structural engineering consultant's modeller and the architect's modeller must talk to each other to assure that model-based design was properly coordinated. Until that time (7th month of the observation period) the modeller of the structural engineer had never attended any DCMs and this was worrying the design manager of the main contractor due to the increasing number of discussions about model-based design and its coordination. At about this time, setting-out drawings were needed as detailed in Event OE 5. In the following DCM, the modeller architect stated that while working on the setting-out drawings, he discovered discrepancies between the linked architectural and structural models. Although he stated that he marked-up the problematic areas and sent them to the modeller of the structural engineer to understand her modelling approach and assumptions, the design manager of the main contractor obliged the structural engineering consultant and the architect to hold a joint modelling workshop to solve all discrepancies.

Another issue about coordination of the model during the detailed design stage was the absence of the sub-contractor information. For example, 'reflected ceiling plans' could not be finalised because the decision about the lighting fixtures and layout was left to the M&E sub-contractor that would ultimately be assigned. Similarly, a curtain wall sub-contractor was needed to be able to finalise the slab-edge details, such as reinforcement details. Absence of these sub-contractors at the time was an important factor in prioritising the work and planning the future work during DCMs. Sometimes this conflicted with the planned workflow which was based on the issue of design artefacts listed in the Information Requirement Schedule (IRS) through the model. In such cases, discussions were held and notes were taken on the IRS about when a particular design artefact would be issued and why it would be delayed (i.e. due to the lack of detail in the model).

The increasing number of the produced design artefacts and the mark-ups on them had to be incorporated in the share model by the architect. This also meant that the architect had to re-issue the previously issued design artefacts that were affected by the updates to the shared model. Although the modeller of the architect aimed to respond to all design artefact issue requests by other members of the design team, sometimes the drawings he issued were criticised for being automatically generated without interpretation and not being sufficiently annotated to facilitate explanation. For example, once the design manager of the main contractor stated that "*I understand that [the modelling software] would bring everything in the section view, but this section looks very confusing*". Similarly, once the senior structural engineer stated that "*[the modelling software] floor plan view makes slab edge line, handrail and plasterboard lines confusing. I had problems understanding that. The software cuts and shows automatically, but does not interpret*".

Meanwhile some other lacks of coordination among various design artefacts had been discovered such as revised occupancy rates not reflected on desk layouts and room data sheets; and the slabs in the risers were not reflected in the model although this issue was expressed by the M&E engineer both during DCMs and through e-mail. These problems necessitated continuous discussions about setting a document control and approval system. A human supervised, document control and approval system was anticipated as detailed in Event OE 6. As shown in Event OE 7, the control system was required to be compatible with the legacy systems of the main contractor, thus, enabling the issue of design artefacts as .dwg files. However, this was somehow a matter of concern for the modeller of architect. He stated that "*when you publish a .dwg file from [a modelling platform], you are never sure if it is the same before you check. When you draw in CAD, you know that it is correct but when you publish from [the modelling platform] you should go and check. I mean it never happened to me and the guys on the site don't work with millimetres; but still...*". With all these developments happening, the modeller of the structural engineering consultant attended the last observed DCM and played an active role in discussions regarding what was in the structural model, what she was currently working on, and what needed to be done to fix the existing discrepancies between the architectural and structural models.

6.3.3. Model-based working as part of the wider organisation (zoom-out x2)

Zooming-out to the level of interrelated practices reveals that, in the OffiBuild project, there was a gradual shift in terms of the effects of model-based working on the wider web of interrelated practices. Initially, the project exhibited limited considerations about structuring and regulating the modelling practices as it was mainly the representative of the architect who interacted with the model and others mainly performed their initial designs based on the generic design artefacts (e.g. initial floor plans) produced by the architect through the architectural model. However, with time, implications of the technological considerations of model-based working on the wider organisational efforts were increasingly felt. This was due to the start of the structural engineer's engagement with modelling, and the needs of other members of the design team that relied more and more on the information in the shared model. This gradual shift is overviewed below with references to the developments in the project which have been presented in the previous section.

At the early stages of the observation period, the model was developed and used only by the architect, and there were no complications caused by various versions of design artefacts or interdependent design artefacts in the project. At these times, in terms of model-based working, the concerns were mostly about establishing the assumptions about what practitioners visually saw in DCMs using models. More specifically, the completeness of the 3D models used in the DCMs contrasted with the initial stages of the design when there was a limited number of taken design decisions. Although having 3D models was appreciated by the practitioners and extensively used to discuss various aspects of the alternative building systems, during the use of models in DCMs there were considerations about what design propositions were included in the shown model, and how close the modelled building systems were to their future physical reality. Practitioners needed to continuously re-consider these issues as part of their interdisciplinary discussions for design development in DCMs every time they used models as visual aid. These were the dominant concerns in terms of model-based working at the initial stages of the project, and can be grouped as technological considerations (i.e. considerations to reveal the assumptions embedded in the representations provided by technology). On the other hand, although the representative of the architect was the only one developing and interacting with the information model at these early times, a version of the information model was accessible to other stakeholders on the online document management system for their inspection. Therefore, various design stakeholders asked questions that were directly related to model-development to the representative of the architect, such as what was currently in the model, what would be updated or modelled next, and when and so on, in order to establish the reliability and legitimacy of the shared model. Consequently, even at these initial stages of the OffiBuild project, model-based working was also a matter of concern for wider interdisciplinary activities.

Over time, with the increasing number of design artefacts produced and decisions taken, concerns about model-based working had become increasingly visible and significant in DCMs. Initially, the main approach of the representative of the main contractor was to keep the modelling concerns out of the sight as much as possible through planning, organising, and tracking the design based on the development and coordination of individual design artefacts, such as drawings and schedules. Nevertheless, architectural design artefacts were essential for the development of design by most other disciplines and they were produced through the architectural model. Therefore, with time, various implications of model-based working in the architectural discipline started to be felt by various members of the design team. For example, even when only one of the façade types of the building was decided to be changed, this resulted in surprisingly long lead times to update the architectural design, thus became an issue for all design practitioners. These implications started to be felt even more with i) the increasing level of development of design in all disciplines which implied an increasing number of different design artefacts that needed to be coordinated with each other; and ii) the decision of modelling structural design in the shared model, and identifying the shared model as the main point of reference for interdisciplinary coordination. Over the observation period, the approach of the representatives of the main contractor to modelling-related issues shifted from avoidance (e.g. planning and tracking the work based upon the documentation requirements of various design milestones), to assessing impacts of modelling to interdisciplinary design in terms of particular emerging issues (e.g. cross-referencing floor plans in the shared model with FF&E schedules), to full-appreciation and enforcement (e.g. obliging architect and structural engineer to hold a modelling workshop to adjust their models). This happened in relation with the problems of coordination in the design team due to the developing design which implied an increasing number of interdependent design artefacts produced by various parties, and the increasing level of detail they included. Overall, the increasing amount of data in the shared model produced interdependent design artefacts based on this data, and the influence of these on the work sequences resulted in an increasing amount of technological considerations, and their extended effects on other interdisciplinary efforts. Consequently, alignment of wider interdisciplinary efforts with modelling activities was an ongoing consideration which was further complicated due to the approach of the design management that focused on individual design artefacts without acknowledging the underpinning modelling appropriately.

The problems with model development in the OffiBuild project also suggested that interdisciplinary model-based working and wider interdisciplinary efforts were interrelated but this interrelation was not acknowledged adequately. Although the representatives of the structural engineering consultancy and architect decided to work with the shared model in turns for ensuring a clear and simple process of model development, they still needed to continuously discuss and address issues about what to include in the model; what not to include (e.g. no reinforcement-bars in the shared model); what had changed in the model since the last discussion; where they were with their designs and how much of them were in the model; whose responsibility it was to set certain things (e.g. setting-out drawings) in the shared model etc. Nevertheless, these conversations were mostly held among the senior members of the architect, and structural engineering consultancy who did not deal with hands-on modelling. This resulted in discrepancies discovered between structural and architectural models which then eventually led to the attendance of the modellers to DCMs. In the OffiBuild project, the lack of understanding of the interrelation between interdisciplinary model-based working and wider interdisciplinary efforts affected mostly the roles and activities of the representatives of the architect who were appointed as the main person responsible for keeping the model up-to-date, in line with design progression, and clash-free.

Finally, there were also considerations which looked purely technological, such as the integration of laser survey data and the information model. However, these also became considerations about organisation of the wider interdisciplinary efforts in the sense that they were not expected by, and affected the works of, those who did not engage with the model-based working. Besides, there were some other purely technological concerns that affected only those who were actively working with the models in their everyday practices and did not affect the wider organisation of interdisciplinary efforts. However, the reason these concerns did not propagate was because they were known to the practitioners who experienced them, and these practitioners continuously resolved them as part of their discipline-specific model-based working. For example, there were problems with the automatic features of the modelling software such as creating automated plan- or section-views which needed to be reviewed, interpreted, and annotated by a skilled professional after automated generation of the artefact. Moreover, the lack of trust in the modelling software in file format conversions was also acknowledged by those who were proficient in using the modelling software.

6.4. Interdisciplinary Model-based Working in the LabBuild Project

6.4.1. An overview of the project-specific context of model-based working (zoom-out x1)

The LabBuild project was observed for a much shorter time period compared to the Edubuild and OffiBuild projects. Nevertheless, it revealed valuable insights regarding model-based interdisciplinary working. Although only six meetings were observed by the present researcher in the LabBuild project, the last four meetings that were observed focused on model-based interdisciplinary working. These four meetings took place shortly after the project architect changed. They can be seen as a series of meetings that aimed to re-establish the interdisciplinary model-based working in the project, which started with the concerns of the client regarding the actuality and precision of the design information models.

The LabBuild project was funded by public money. The bid manager of the main contractor told the researcher that although the client did not have much knowledge about BIM, the client and the main contractor were agreed that BIM would be used for the design of the project as part of the UK government push for BIM use. The bid manager of the main contractor claimed that the client organisation seemed to ask for the use of BIM as a perfunctory measure (i.e. "*just to tick the box*"). He further stated that, for this reason, the client did not know what to expect or how to specify the requirements from the model and the main contractor assisted them in the inclusion of the BIM-related scope of works in the contract. Consequently, a design building information model was agreed to be developed to BIM Level 2 and used as part of the design project but there was not a detailed BIM protocol or Employer's Information Requirements established in the project.

The LabBuild project was a fast-tracked design-and-build project in which the priority was given to the steel structural system design in order to be able to start the construction on site as soon as possible. For this reason, the design of the steel frame was quickly developed in combination with the conceptual design of other building systems (e.g. architectural and M&E). Before the start of the observation period, some clash-detection meetings were held in order to assure that the design had no major clashes among various systems. Clashes among the following sections were checked through the clash-detection feature of the modelling software before the steel structure construction started:

- Structural frame versus M&E
- Floor plates versus M&E
- Architectural wall versus M&E
- Architectural walls versus structural frame
- Architectural walls versus clean rooms

The next section will describe the orientation of the model-focused meetings that were observed in the LabBuild project.

6.4.2. Orientation of the interdisciplinary interactions concerned with model-based working (zoom-in)

<u>Meeting 1: Expectations of the client from the model and the reaction of the design team</u>

This meeting was held upon the request of the client to get the design model for coordinating the purchase and installation of the specialist equipment that would be purchased and installed in the clean rooms by the client. The client needed the correct and precise details of the design in order to make sure that the equipment they would order would fit into the planned locations through the planned service connections. This equipment was custom made and required a high level of precision in terms of its location in the clean rooms, therefore, the client was highly concerned about having a fixed design of the clean rooms before ordering the equipment. The client thought that the checks, calculations, and controls they needed to do before the purchase of the equipment would benefit from a virtual installation of the specialist equipment in the model, and therefore asked the designers to provide an accurate and sufficiently detailed version of the design model.

At the beginning of the meeting, the aim of the meeting was stated by the project manager hired by the client (client PM) as "*seeing where the team is in terms of the model and the expectations from the model*". The meeting was organised by the design manager of the main contractor but he could not be present at the meeting for external reasons. The BIM manager from the headquarters of the main contractor replaced him for this and the other three meetings observed by the researcher. The client PM claimed the model was falling behind what had been built, and also there were inconsistencies in designers' discipline-specific models. One of the representatives of the client organisation stated that clashes could easily have been detected by coordination through information models, and that they had already detected a potentially time-consuming and costly clash at the clean rooms when they were working with the clean room sub-contractor. He then added that they wanted to use the model for such purposes. Upon this statement, the BIM manager of the main contractor and the architect began to ask questions to the representative of the client organisation regarding what exactly they needed the model for, and therefore what level of detail of modelling was needed for the parts of the building that they wanted to coordinate using the information model. When the BIM manager of the main contractor asked "*how accurate does the model need to be?"*, the representative of the client organisation who was responsible of the procurement and installation of the specialist equipment stated that they needed a "*practically accurate model*" in order to make decisions, checks and controls regarding the equipment that would be purchased and installed. The discussions that took place following these initial conversations included the questioning of the actual situation of the model, the reasons behind that, the specific expectation of the members of the client organisation of the model, and the reactions of the design team in the face of the requests of the client.

The actual situation of the model and the discrepancies between the model and the work on the site became an issue when the members of the client organisation asked to have the model for the purposes of purchasing bespoke specialist equipment and learned about these discrepancies. During the meeting, it was explained to the representatives of the client organisation that the construction had been done according to the sub-contractor's drawings. The site dimensions then had been fed back to the designers to ensure that the dimensions on the sub-contractor drawings were consistent with the dimensions in the model. The representatives of the client organisation were told that this was a periodical exercise rather than a one off, wholesale exercise. On the other hand, the members of the client organisation insisted that the correct dimensions were needed to the precision of two millimetres for the coordination of the specialist equipment that would be installed. Moreover, the members of the client team also added that they would like to use the model for the future maintenance operations of the building as well.

Although, this was the first involvement of the BIM manager of the main contractor with the project, most of the questions and comments were directed to him by the client as he was replacing the design manager of the main contractor. The BIM manager of the main contractor asked the other members of the design team whether there was a list of discipline and sub-contractor specific models and components, but he did not get a reply. He claimed that according to the information he had, it was agreed with the client that the building information model would be developed for design and high-level construction coordination. He added that this implied that the production level of details (i.e. as-built details to the precision of millimetre) would not be in the model. This statement triggered other negotiations about what needed to be included by the designers in the model and at what levels of detail. The M&E engineers claimed that often in the design meetings they asked what BIM level 2 was and did get an answer. Moreover, they posited that it never involved modelling to the level of detail of small power and sockets (which was now asked by the client for the coordination of the specialist equipment).

The client complained that previously the need for coordination between the specialist equipment and M&E systems were expressed and they were told that there were problems with the model and the problems were still there. It was decided that the client placed the specialist equipment in the existing model and then had a meeting with the M&E engineers. This meeting was deemed to be useful both for the planning purposes of the client and for the identification of the critical interfaces for the M&E engineers. Following this, the members of the client organisation posited that the 3D objects of the specialist equipment that they had were very detailed and they did not know how these could and should be attached to the existing design information model. The negotiations took place to figure out the best way to incorporate the 3D equipment objects that the client had in the design information model.

The topics of what was going on the site, what was in the model, and how correct the actual design model was, started to be negotiated again. The client PM claimed that different people knew different pieces of information about the design on the site and in the information model, and these were not necessarily coordinated. The BIM manager of the main contractor stated that he needed to understand the agreed level of detail at the outset of the project with the client. He further stated that he needed to investigate more the current process of feeding information from the site to the model. The representatives of the client organisation highlighted the most important areas in terms of equipment installation, and the representative of the architect argued that it was good to learn about the most important areas so that they could focus first on those areas in the model. The client PM still complained that it had been four months since those issues with the model were pointed out. The main contractor was seen as the main responsible to put the model back on track by the client PM and the representatives of the client organisation.

Meeting 2: Exploring the current situation of the model-based interdisciplinary working

After the Meeting 1, which was held with the team of the client, the BIM manager of the main contractor wanted to have an additional meeting with the representatives of the clean room sub-contractor and the architect in order to have a clearer picture of the current situation of the model, the site, and the current model-development process. The architect started her conversation by arguing that they did not have time to create as built drawings of the areas that were asked by the representatives of the client organisation. She claimed that at the end of the design they could, but not at that moment. The representative of the clean room sub-contractor stated that they worked with 2D drawings on the site because they had been asked by the members of the main contractor to do so in order to progress quickly on the site. He claimed that the steel work on the site was not in line with the architect's drawings and not even in line with the steel works sub-contractor's own drawings. He added that even the steel columns were built outside of the twenty millimetres tolerance that was allowed. He further claimed that the newly appointed architecture company had recently realised that they were working with different versions of information after noticing some clashes on the site. As a result of this, the architect asked the clean room sub-contractor not to progress further with the works until the wall layouts and ceiling heights were fixed by the architect.

The representative of the architect stated that their model was at 1/50 level of detail and the construction of the clean rooms had some deviations within the allowed tolerances. She argued that was why the request of the client to have the model at two millimetres precision could not be satisfied with the current model. She further claimed that the clean room sub-contractor and the architect knew where the tolerances were, but the members of the client organisation did not and that was why the members of the client organisation thought there were more clashes than there really were.

The representative of the clean room sub-contractor argued that when the architect of the project was changed, some discussions took place between the old and the new architect and the main contractor, but their company were not informed about those discussions. He argued that probably the parties directly involved thought that all the parties that needed to know about those discussions were part of it but the clean room sub-contractor was not informed about them. The representative of the clean room sub-contractor argued that this was the reason for the clashes that happened on the site in the clean rooms.

After these explanations the BIM manager of the main contractor started to express his thoughts on what needed to be done. He stated that he needed to talk to the people who managed the contract negotiations with the client in order to understand what level of detail of modelling was promised to the client. Both the architect and the clean room sub-contractor claimed that if what was being asked was more than what was promised initially, then additional payments would have asked for from the client. The BIM manager of the main contractor also stated that a responsibility matrix for the model (i.e. in terms of which discipline owns which objects in the model), including the sub-contractor design would be needed. The architect claimed that most of the sub-contractors were not BIM compatible but the BIM manager insisted that the matrix was still needed and the responsibility of modelling the sub-contractor design would be on the shoulders of the main designers who were BIM compatible. He also stated that the current status of the 2D drawings also needed to be known.

The BIM manager of the main contractor then stated that the client should be given a locked-down version of the model only with what he wanted to see and the architect agreed. He then asked how far the architect was with the update of the model according to the construction on the site. The architect stated that they were busy doing that with few more things to do such as changing the doors to the correct types because the doors were represented by generic door objects at that moment. She then asked again the BIM manager of the main contractor at which level of detail they were required to update the model because the level of detail articulated by the client would require extra time, effort and payment. She further stated that the architectural model that they were handed from the previous architect did not match with the work on the site and therefore they started to gradually update it. However, she claimed, the parts they had been updating since they started uncovered discrepancies that were not fixed in the structural model.

The BIM manager stated that he would try to understand the requirements of having the level of detail asked by the client in the model. He posited that it was clear that the exact positions of the specialist equipment were a critical issue and needed to be carefully coordinated with the services connecting to them. He concluded that, therefore, wherever this specialist equipment would go should have a higher level of detail, less tolerances (more precise measurements) and more-detailed objects than the rest of the model in order to ensure that the equipment was coordinated adequately.

Meeting 3: M&E sub-contractor and client coordination meeting

This meeting was held upon the request of the members of the client organisation to carefully coordinate the areas where specialist equipment would be installed. Owing to the fact that there were problems with the precision and actuality of the model, it was decided to have a coordination meeting between the M&E engineers and the future manager of the building for a detailed negotiation about the areas where the equipment would be installed. The BIM manager of the main contractor attended the meeting as well because the design manager of the main contractor was still absent (i.e. he was on parental leave).

The M&E engineers and the member of the client organisation were in front of a computer screen where the design information model was shown. At the same time there were many 2D printed drawings of the electrical and mechanical services as well as architectural plans on the table. The BIM manager of the main contractor was in the same room but working separately. He was doing checks in the discipline-specific models that he was handed the previous week and also walking through the merged models to see the problems and clashes in the integrated model (i.e. structural, architecture, and M&E). The model that the member of the client organisation and M&E engineers were working with included the objects of the specialist equipment provided by the client. Through looking at the model, the member of the client organisation was reflecting upon and describing in detail what kind of power, data and process water services would be needed and where, according to the specialist equipment that would be installed at specific locations. Moreover, the member of the client organisation was also telling which areas had to be cleared around the equipment considering the special piping requirements of the equipment. In this respect, he used narratives that described the roles of the equipment and the way they would be used. The M&E engineer mostly took notes on the 2D drawings regarding the types, numbers and special requirements of the services that would be provided at each spot that was discussed. Sometimes, the negotiations became so detailed that even the orientation of the manifolds on the water pipes were considered, bearing in mind the potential intervention of the manifolds with the operation of the equipment.

During this exercise some discrepancies between the 2D drawings and the model were discovered. For instance, at one of the locations the number of the landings of the stairs was different in the model and in the 2D drawings. The discussions about the level of detail that the model would have again took place. The M&E engineer stated that the detailed information such as the individual sockets would not be in the model but on the updated version of the schematic drawings on which the electrical engineer took notes on. The member of the client organisation occasionally reminded that special types of walls would be used in the areas where the specialist equipment would be installed. The discussions about the installation details of the M&E end points and the efficiency of data outlets needed to take into account these special wall types. After the first two hours, the member of the client organisation and the M&E engineers decided to visit the site in order to see the current situation on the site before further progressing, and also to see the areas that they had already discussed on the site. The site visit referred a great deal to the previously held discussions in the meeting. The discussions on the site included: what had been installed so far, what would be installed next and the connections of these with the installation and operations of the specialist equipment.

After the site visit, before further progressing with the coordination of the M&E services and the specialist equipment, the member of the client organisation asked the BIM manager of the main contractor whether the level of precision required could be achieved in the model. The BIM manager answered that what they could and could not achieve was more about what they *should* have achieved. The client stated that he understood the less precise nature of the construction, but high precision was required for the installation of some equipment. Then it was agreed to visit the site regularly in the future as it would be beneficial to achieve the precision required for the coordination of the sensitive areas.

The M&E engineers and the member of the client organisation continued to go over the locations where the specialist equipment would be purchased and installed by the client organisation. This sometimes included tensions where the client told the M&E engineers to model their information correctly and then if the client could not install their equipment, they would take the responsibility. The discussions were based on approximate locations where the equipment was planned to be installed. This was because there was no sensitive measurement in hand that could be used for the detailed coordination. The member of the client organisation continuously stated that when the walls were built, a site investigation could be undertaken and final decision could be taken for the exact positions of data-, power- and water-outlets. At the end of the meeting, the M&E engineers told the member of the client organisation that they needed to incorporate all the discussions they had with him in the drawings in order to see what they could do and what were the risky areas that would need special attention. The member of the client organisation agreed with this and added that more iteration was needed for the coordination of the specialist equipment with more concise drawings reflecting the actual situation on the site. The member of the client organisation finally added that if the installations on the site were within the allowed construction tolerances then it would be acceptable to work with the existing design models, but in cases where there were deviations of 100-200 millimetres then the model would need to show the real dimensions for successful coordination.

Meeting 4: Planning to put the model back on the track

This meeting took place on the same day after the Meeting 3. This was a follow-up meeting of the model planning meeting (i.e. Meeting 2) which had taken place the previous week. Over the previous week, the BIM manager of the main contractor investigated the promised level of detail to the client and came up with some general strategies about how to put the model back on track and how to deal with the client's requests regarding the model. Before the meeting, during an informal chat, the BIM manager of the main contractor told the researcher that in the contract it was clearly stated that a design model would be delivered and therefore no manufacturer information, which includes secondary steel construction, was the modelling responsibility of the design team. The BIM manager told the researcher that a laser cloud point survey was considered in order to quickly understand the condition on the site and reflect the current situation to the model.

The BIM manager undertook a clash-detection exercise, examined the detected clashes and walked through in the merged model during the M&E engineers and client coordination meeting at the other end of the meeting table. Consequently, he came to this meeting with a list of clashes and an idea of the current situation of the discipline-specific models. Moreover, he also attended the site visit that was done during the meeting in the morning (i.e. Meeting 3) and therefore he had an idea of the situation on the site as well. The M&E engineers and the representative of the architect attended this meeting. In the meeting, the BIM manager started with presenting a list to the other attendants. This was a list with multiple columns. The first column included the information that needed to be included in the model in terms of design elements, such as roof drainage, wall finishes, cubicles etc. The elements in this column were very comprehensive and included more-or-less all parts of the building. The second column was to assign a responsible consultant to provide corresponding information in the model. The third column was to specify at which stage of the design the information would be provided. The fourth column was about the level of detail of the information that would be provided. The final column was to note specific coordination requirements for that part of the model/design. The BIM manager wanted to fill in the table together with the M&E engineers and the architect. The engineers and the architect agreed to do this exercise but noted that the structural model was not updated within the last six months and did not reflect the current situation on the site. The BIM manager explained to them that through the work allocation that would come out of this exercise, how the structural elements could be updated would be clearer to all parties. During the exercise, the M&E engineers and the architect agreed on taking on the responsibility of modelling for their trade sub-contractors because they claimed that most of their sub-contractors were not BIM compatible.

This exercise allowed the attendants to discuss each of the elements listed in the first columns from the modelling point of view. For example, when the kitchen fittings were discussed, the architect told the BIM manager that the kitchen fittings were represented as empty boxes in their model and the BIM manager agreed with that level of detail. The modelling interfaces between the M&E engineers and the architect were also discussed during the exercise. For example, in the reception area there were doughnut-shaped lights and acoustic baffles. They were in the architectural model at the time, but the lights needed to be transferred to the M&E model and therefore required special coordination. Some other similar transactions between the architect and the M&E engineers were planned to be coordinated through the use of the placeholder objects that would first be created by the architect until they were swapped with the finalised M&E objects. Other interfaces between the M&E and architectural models required other solutions. For example, the BIM manager asked the M&E engineers to copy and paste the sanitary furniture from the architectural model and show the corrections on them. Another concern was the representation of the FF&E in the architectural model. This was an issue because the client had the responsibility for the procurement and the installation of the FF&E. The architect claimed that although that was not under the responsibility of the architect, they helped the client a lot with that and therefore had some drawings. Nevertheless, the architect stated that because the FF&E were not under their responsibility, they did not want to include them in their information model but rather to keep FF&E drawings separate in the sketching software. The level of detail column opened up many discussions around which information regarding a specific group of elements would be provided as 2D and which as 3D.

After the completion of the exercise, what the attendants of the meeting would do next started to be discussed. During this discussion, the M&E engineers and the architect stated that the building was split into two phases that had been progressing differently. The Phase 1a of the building was at Stage 5 and the Phase 1b was at the Stage 1. The M&E engineers and the architect asked questions about how this could be managed. The M&E engineer stated that the services plans needed to be connected between the two phases in the model and therefore creating another project for the Phase 1b was not feasible. Moreover, designing unclosed M&E systems in the modelling software caused ceaseless calculations by the software significantly reducing the speed of the software. The BIM manager told the attendants of the meeting that the shared modelling platform had an in-built phasing feature to manage the phasing in the projects. The members of the design team told him that use of that feature was not planned at the beginning of the project and they did not know how to make use of that feature at this stage of development of design. The architect stated that she wanted to generate a sheet for Phase 1b and the modelling software automatically named it as Stage 5 whereas the Phase 1b was at Stage 1. The BIM manager said that the visibility and legend of the drawings could be customised to reflect the correct phase and stage.

The last part of the meeting was about the results of the clash-detection exercise that the BIM manager undertook during the meeting in the morning. Although there were many out-of-date entities in the models, the BIM manager ran a clash-detection exercise and quickly went over them. The BIM manager picked the clashes that he thought could be important and discussed them with the other participants of the meeting. As a result of these discussions, it was discovered that some of the clashes detected were already updated in the drawings and/or the work-in-progress models of the architect and M&E sub-contractor; some of them were known and would be resolved in the design or on the site, and some of them would be examined in more detail after the meeting. The clash list constituted 333 pages in total but the BIM manager asked the members of the design team to go over only the clashes that were accompanied by a snapshot next to them.

6.4.3. Model-based working as part of the wider organisation (zoom-out x2)

The meetings presented above revealed that the main considerations in enabling interdisciplinary model-based working through the observed series of meetings were about establishing the 'actuality' and 'accuracy' of the model. Practitioners needed to establish both the current and target 'actuality' and 'accuracy' of the model in order to be able to make sense of its legitimacy and usefulness in the project. Nevertheless, establishing the current and target 'actuality' and 'accuracy' required numerous discussions and meetings where various stakeholders were asked about their knowledge and understanding of the 'actuality' and 'accuracy' of the model. This involved various references to the particularities of working in the shared modelling environment, and the corresponding concerns and responsibilities. These discussions enabled the practitioners to negotiate the current and target levels of 'actuality' and 'accuracy' in terms of the corresponding technological requirements and the implications of working with such models. Therefore, the meetings presented in the previous section were for aligning the technological requirements of model-based working, with what they meant for various practitioners who had stakes on it.

For example, the first meeting was for discussing the client expectations from the model, which corresponded to exploring the way of working with the model desired by the client organisation. This discussion involved unavoidable references to the levels of detail that needed to be present in the model to meet the desires of the client organisation. The arguments about the levels of detail required in the model triggered further discussions about how the connection between the site works and model were held. Consequently, the interpretation is that establishing the current and target 'actuality' and 'accuracy' of models required alignment of technological requirements of model-based working, and the corresponding implications of working with such a model from multiple perspectives. This was implicit for example in the M&E engineers' criticism that often they asked what 'BIM level 2' implied but they had never had a clear reply from the main contractor. Moreover, the client Project Manager stated that different people knew different parts of the site works and the situation in the model, but these were not necessarily coordinated. Therefore, this discussion in the first meeting was indeed an expression of the confusions due to the unarticulated need of aligning certain ways of working in the model with their implications on the wider organisation of the work. The confusion was evident in the struggles of the practitioners in expressing their needs and concerns about model-based working. They used expressions such as a '*practically accurate model*' which meant that the level of detail they needed in the model actually depended on their purpose for using it. In this respect, the discussion involved appreciating and adjusting both work requirements of multiple disciplines and corresponding roles and responsibilities for modelling. As a result, the discussions required both appreciation and adjustment of the way the technology works and the ways others (want to) work with technology.

Moreover, contractual issues were considered in evaluating the requests of the client regarding the model from the beginning of the reported series of meetings. This showed that how the changes about working in the model would have significant impacts on the efforts of design development through that model. Once it was understood that there were misalignments between the modelling practices and wider interdisciplinary efforts of design development, the subsequent meetings aimed to establish the differences and reconcile them through discussions. For example, the last two meetings that were observed were oriented towards establishing:

i) the different ways practitioners in different disciplines had been working with the model and the corresponding ways that they had adopted for modelling (i.e. the coordination workshop that was held between the client representative and M&E engineers; and the interdisciplinary discussions that were held around the list of components that would be modelled);

ii) the implications of these differences as variations between the site works and documented design in models and drawings (e.g. decision to conduct a laser point cloud survey, site walk-through), and the problems in the model (e.g. clash detection exercises and model walk-through).

Consequently, it can be argued that the interdisciplinary discussions that were held along these four meetings were seen as laying the foundations of a healthy interdisciplinary model-based working state rather than being conclusive. Practitioners worked on establishing a shared understanding of current and target 'actuality' and 'accuracy' of the model through various meetings and discussions in which they aimed to align their ways of modelling and evaluating the corresponding wider implications. According to the findings, the parties planned for further interdisciplinary interactions as a way of establishing and maintaining this shared understanding when they discovered differences and problems about both modelling and the role of models in the wider organisation of the work. The need for further interactions was explicitly stated, for example, at the end of the third meeting when the participants of the meeting agreed on holding further coordination meetings and site visits to align the situation on the site and in the model. Moreover, the parties continuously stated that decisions about the level of detail in the model must be underpinned by the joint consideration of both the requested and feasible levels of detail for various parts of the model (i.e. various building systems). Similarly, the conversations about the accuracy of the model centred upon aligning the various expectations and requirements of the involved parties (e.g. contractual obligations for the members of the design team; high precision coordination needs for the client etc.). Therefore, although the reported series of meetings started with frustration and confusion due to non-negotiated ways of model-based working and the handling of its wider implications, interactions that ensued revealed that ongoing negotiations are needed to establish and maintain meaningful interdisciplinary model-based working.

6.5. The Practical Concerns and Lived Directionality of Interdisciplinary Model-based Working

Drawing on Nicolini (2012), this chapter focuses on the 'oriented and concerned nature' of interdisciplinary model-based working in order to establish how practitioners made sense of what to do, and what ought to be done in terms of interdisciplinary model development and use. The aim of this chapter is to bring forward the 'lived directionality' (Nicolini 2012), which drives the interdisciplinary model-based working, and hence, enables 'making sense of' and 'organising' interdisciplinary model-based working. First, the project-specific contexts of model-based working are presented followed by the presentations of the orientations of the interdisciplinary interactions concerned with model-based working in each of the observed projects. This involved the presentation of the accounts of what the practitioners needed to discuss, where they directed their efforts to, when and how, in order to make sense of what to do and what ought to be done for model development and use. Following this, the study zoomed-out to the level of interrelated practices in each project in order to further explore the extent and impact of interdisciplinary model-based working on the wider organisation of the work. In this section, the findings presented in the previous sections are thematised into two overarching 'practical concerns', which provide an explanation of what was it that was achieved through interdisciplinary interactions concerned with model-based working. Following this, a theoretical explanation about the 'lived directionality' which drove the interdisciplinary model-based working is developed based upon the established themes of 'practical concerns'.

The findings suggest that the practitioners had two major kinds of 'practical concerns' in making sense of what to do, and what ought to be done in terms of interdisciplinary model-based working. One of them was about working 'in' the model. The model-based work required a rigidly structured approach that considered the internal procedures of the software as well as regulation of the interactions with the software. This structured and controlled nature of model-based working diverged with the evolving needs of multiple parties, and hence, the models were subject to ongoing discussions to remain as accountable sources of information. This corresponds to the first major theme of practical concern in interdisciplinary model-based working which is jointly establishing a way of '*working 'in' the model*'. On the other hand, in the studied projects, the model became an essential means of interaction and communication, and hence, the particular needs of model-based working affected the wider interdisciplinary efforts and organisation of the design projects. This corresponds to the second major theme of practical concern in interdisciplinary model-based working which is jointly establishing a way of '*working 'with'* *the model'*. Consequently, the two practical concerns of interdisciplinary model-based working are argued to be jointly establishing the ways of '*working 'in' the model'* and '*working 'with' the model'*.

Furthermore, the findings suggest that the practical concerns about *working 'in' the model* and *working 'with' the model* were entangled and involved each other in complex ways requiring interdisciplinary discussions to keep the model-based working legitimate, consistent and meaningful for various parties and purposes. Therefore, this chapter establishes the 'lived directionality' which drove the interdisciplinary model-based working as the '*continuous re-alignment of working 'in' the model, and working 'with' the model*'. In the next section, implications of the established 'oriented and concerned nature' of interdisciplinary model-based working are discussed to develop an explanatory organisational concept.

6.6. Discussion and Concept Development

Using a digital information model as the main hub for design documentation requires all stakeholders of the project to add to, and use the digital design data depository (i.e. the model) through a collaborative effort to ensure the integrity of the data for all parties (BIM Industry Working Group 2011; UK Cabinet Office 2012; Whyte et al. 2016). Consequently, in BIM-enabled projects, there is a need for extra interdisciplinary effort to enable interdisciplinary model-based working, which arises from the collective use of the information model. Collective development and use of a shared model ('the model' henceforth), and its storage in a shared platform, require consistency. The analysis suggests that, in practice, it is essential to continuously spend efforts towards interdisciplinary reconciliations regarding both *working 'in' the model* and *working 'with' the model* to establish and maintain this consistency.

The first one is to jointly establish a consistent way of *working 'in' the model*. The way of *working 'in' the model* is highly influenced by the rigid structures and procedures that are inscribed in the software by its developers in order to integrate and process digital design data. Appreciation of, and respect for these structures and procedures are essential for technology to function properly and deliver the expected benefits. Therefore, on the one hand the technological data-processing structures and procedures, on the other hand modelling conventions that acknowledge these structures and procedures, need to be developed and strictly followed (e.g. conventions around object naming, ownerships, families, modelling sequences etc.) to establish a consistent way of *working 'in' the model*.

Importantly, the findings suggest that, in practice, the way of *working 'in' the model* is not universal and it needs to be adapted to the different needs of different construction projects for meaningful interdisciplinary model-based working. Nevertheless, in the observed projects, the way of *working 'in' the model* could be adapted only to the extent that the software allowed it through its various embedded features that were also based on its underpinning structures and procedures. Critically, the results of this study suggest that such an adaptation can only be achieved through continuous interdisciplinary interactions about i) different expectations from model-based working; and ii) different discipline-specific modelling practices. Successful adaptations were achieved when such interactions were directed towards enabling a joint appreciation of the limitations and capabilities of the software in relation to various and changing needs of different design practitioners. Consequently, according to the findings of this study, maintaining the consistency required in terms of *working 'in' the model* cannot be achieved through one-off re-structuring of the traditionally established design tasks (i.e. standardisation of tasks/processes) based upon the requirements or strengths of BIM technologies. Rather, such a consistency requires ongoing interdisciplinary negotiations about the limitations and opportunities perceived by various design practitioners in relation to model-based working along the project. Nevertheless, albeit these negotiations seem to take place for the adaptation of the software to the specific needs of project, the results suggest that they also transform the traditional design tasks as they reveal novel ways of framing the traditional design tasks (see for example Kitchin 2014; Kitchin & Lauriault 2014).

The second main kind of practical concern that enables the consistency required for meaningful interdisciplinary model-based working is jointly establishing a consistent way of *working 'with' the model*. Models, as a major means of design communication, act as legitimate and accountable mediators of design development only to the extent that the structures and procedures enforced by model-based working (i.e. rigid technology) are in-line with the wider professional needs and considerations of various practitioners. The findings suggest that, interdisciplinary discussions that are held regarding *working 'with' the model* establish, re-confirm and, at times, amend the accountability and legitimacy of the model in terms of the changing needs of various stakeholders and the extent to which the software can respond to these. In this sense, the practical concerns about *working 'with' the model* put model-based working into a larger organisational perspective to determine its position in the wider organisation of interdisciplinary efforts. However, importantly, different design practitioners have different priorities and understandings of what is needed in the project, and therefore negotiations about *working 'with' the model* were not always smooth, and involved competing interests and power struggles at times (e.g. Events EE 5 and EE 6). As evidenced in Event EE 6, the rigid structure of BIM technologies can be opportunistically used as a leverage in such negotiations by those who have more control and/or knowledge about the technology (i.e. the main contractor used the argument that a model is not only for design in order to force the architect to create the model in a certain way). Consequently, interdisciplinary interactions about *working 'with' the model* do not only enable a consistent sense of the roles, legitimacy, and accountability of the model in a project. These interactions also influence the wider organisation of interdisciplinary efforts by enacting interdisciplinary model-based working as a continuous and fundamental concern for all the parties involved in accomplishing the design work.

Ultimately, in terms of addressing Research Question 3 (How is interdisciplinary model-based working accomplished in practice? How do people make sense of interdisciplinary model-based working?), the findings of this study suggest that various practitioners in interdisciplinary design projects come to a shared understanding of the assumptions and suppositions embedded in model-based working through the continuous re-alignment of *working 'in' the model* and *working 'with' the model*. It is these continuous re-alignment efforts that enable practitioners to make consistent sense of what to do and what ought to be done in terms of interdisciplinary development and use of models. In terms of addressing Research Question 4 (What are the connections between model-based working practices and other interdisciplinary efforts?), the findings suggest that the need for consistency in interdisciplinary model-based working creates a continuous need for interdisciplinary negotiations about *working 'with' the model* to jointly position it in the wider interdisciplinary efforts to accomplish the project. These negotiations are unavoidably informed by *working 'in' the model,* or more specifically, by the novel ways of framing design tasks underpinned by the requirements and capabilities of the modelling software. Therefore, these negotiations enact model-based working as an essential concern for the accomplishment of design work; and thus, affecting the wider organisation of interdisciplinary design work. It is through this practical mechanism that interdisciplinary model-based working and other interdisciplinary efforts affect and shape each other on an ongoing basis.

When considered together, these results point to an ever-evolving, jointly constructed, and therefore a shared epistemological position within a design team, as the basis of reasoning in developing and using information models in design projects. In this study, this shared epistemological position, or basis of reasoning in interdisciplinary model-based working is called '*technological premises'*. The concept acknowledges the ongoing mutual shaping of technological considerations/opportunities and wider professional needs/agendas. However, the word 'technological' is used intentionally in naming the concept in order to underline the major influence of the rigidly structured way of working of BIM technologies on wider practices of interdisciplinary design in construction. According to this conceptualisation, establishing and maintaining technological premises is crucial to assure consistency, and therefore for meaningful interdisciplinary model-based working in a design project. However, at the same time, it is this ongoing need for maintaining consistency in the face of a rigid technology that gives model-based working the power of affecting wider interdisciplinary efforts; and hence making technological premises an organisational concept that involves not only technological operations but also the wider organisation of design work.

The findings suggest that the consistency and coherence needed in the use of shared modelling platform can be only partly established through rules, standards and regulations such as contract clauses, responsibility matrices, BIM protocols and so on. These instruments provide a degree of shared understanding on the joint use of the shared modelling platform and therefore put some of the automated and human-driven data operations into perspective. The constructs that these instruments employ and the procedures that they describe, enable different members of the design team to have a common vocabulary and similar understandings about the constructs and the way shared modelling platform can and should work. As a result, members of design teams become enabled to liaise regarding data operations, and how they can, and should, collectively work with data and shared modelling platform.

Nevertheless, the design is a developing artefact, and this process of development is unique and non-routine. Consequently, not every contingency can be documented and therefore insofar as the work and the technology are non-routine, people need to develop and maintain project and situation specific shared understandings around working with data and ICT. Therefore, technological premises need to be re-confirmed or developed on an ongoing basis and the assumptions behind them should be checked and re-evaluated continuously in order to keep information models as legitimate and accountable sources for both individual and interdisciplinary working. The findings suggest that in practice this ongoing process has been undertaken through ongoing model coordination and clash detection meetings, conversations around the contents and versions of the models, conversations around the intentions behind the modelled objects and their timing, different roles specifically related with model development and their separate internal meetings, strict ICT-based validation processes, federated model management approaches (i.e. *working 'in' the model*) as well as additional ongoing interdisciplinary interactions focusing on *working 'with' the model*. It is through these past and ongoing social interdisciplinary interactions that shared understandings of how to work with models was established and maintained, the consistency and coherence needed in human-computer interactions were satisfied, and thus meaningful ICT-mediated work was reached. At the same time, it is again through these interactions that the change underpinned by model-based working was generated, and diffused in the traditional design tasks.

CHAPTER 7. DISCUSSION

7.1. Introduction

The practice-based view of 'organisation' ('organising') adopted in this research suggests that all organisational phenomena are continuously accomplished in practices through the ongoing interactions among people and materials. In view of this, the findings and analysis chapters (i.e. Chapters 4, 5, and 6) provide explanations about the activities that enabled 'organising' in the studied projects. Similarly, the organisational concepts developed at the end of each of these chapters are explanatory in the sense that they depict the ongoing processes and efforts of accomplishing the organisation through practicing. By setting different empirical foci for each of Chapters 4, 5, and 6, this research foregrounds three different sets of activities and processes that were part of 'organising' the observed projects. Chapter 4 shows the necessity and process of establishing and maintaining a shared epistemological position regarding interdisciplinary design development in order to enable consistency and coherence. This is captured through the explanatory concept of 'organisational premises'. Chapter 5 shows how design artefacts were purposefully created and employed as part of the process of organising. This is captured through the explanatory concept of 'purposeful artefact'. Chapter 6 shows the necessity and process of establishing and maintaining a shared epistemological position regarding the interdisciplinary model-based working in order to keep the ICT-related operations running and meaningful for practitioners. This is captured through the explanatory concept of 'technological premises'. These concepts do not constitute a conceptual model based on cause-effect relationships. Rather, they show how each set of foregrounded 'doings and sayings' contribute to the accomplishment of BIM-enabled interdisciplinary design work, thus, providing a rich description of its organising. This chapter takes stock of this rich description, and uses it as the starting point for discussion to highlight the contributions of a practically relevant conceptualisation of BIM-enabled interdisciplinary design work in construction, and a corresponding understanding of its ICT-driven change.

This is done in three main steps. The first main step is to delineate the practice-based understandings of 'organising' (Section 7.2.1) and 'order' (Section 7.2.2) in BIM-enabled interdisciplinary projects by highlighting the unique insights garnered from this research. From a practice-based view, organisational structures and order are the patterns of activities that can be observed at higher (i.e. more abstract) levels of organisation but are rooted, and continuously re-produced in everyday practices (Schatzki 2001; Feldman & Orlikowski 2011; Nicolini 2012). Therefore, Section 7.2.2 discusses 'order' in BIM-enabled interdisciplinary design projects in terms of the practice-based understanding of 'organising' developed in Chapters 4, 5, and 6. The second main step is to use the established practice-based understandings of 'organising' and 'order' to discuss the high-level constructs relevant to contemporary design work in construction. In this respect, Sections 7.3.1, 7.3.2, and 7.3.3 aim to refine the constructs of 'design', 'design collaboration', and 'ICT (in design in construction)' respectively from the practice-based perspective developed in this research. The third main step is to present an overarching discussion of 'ICT-driven change in interdisciplinary design in construction' (Section 7.4) in relation to the previous empirical research on ICT and organising design in construction. Overall, the chapter contributes to achieving the aim of the research in enabling a better-informed engagement with the change fuelled by the technologies of BIM through the discussions about the practice-based views of 'organising' and 'order', and the implications of these on understanding the constructs of 'design', 'design collaboration', 'ICT (in design)', and 'ICT-driven change' in construction.

7.2. 'Organising' and 'Order' in Interdisciplinary Design Projects in Construction

7.2.1. 'Organising' in interdisciplinary design projects in construction

Design in construction requires different stakeholders with different backgrounds and foci to work together and to purposefully integrate the different sets of skills and knowledge that they possess. Understanding organisation of design in construction requires an understanding of how these differences temporarily come together, co-exist, and are combined in purposeful ways to accomplish the design work. It has been shown that a good appreciation of this complexity and variety inherent in such organisations is critical to enable innovation (Harty 2005; 2008) and collaboration (Cicmil & Marshall 2005). This research shows that adopting practice-based views of 'knowing' and 'organising' (see Section 2.2), have the capability of accommodating the inherent complexity and variety in design practices in construction. From a practice-based perspective, the complexity and variety become the starting points to understand and theorise about organisation of design in construction, and thus, enable significant contributions both for its theory and practice. In this section, these are discussed both to highlight the unique aspects of the view of 'organising' interdisciplinary design in construction established in this study, and how these correspond to capturing its inherent complexity and variety.

First, practice-based views of 'knowing' and 'organising' in interdisciplinary design work open up the 'black-boxed[6]' concepts and notions that are used in researching, understanding, performing and managing it, and thus, avoiding over simplification of the organisational phenomena. From a practice-based perspective, 'knowing' is the 'knowledgeability' of what to do and what ought to be done in the ongoing flow of practices (Orlikowski 2002; Sandberg & Tsoukas 2011). Design professionals with different professional and personal backgrounds, foci, and skills attach different meanings to design work, implying that they have different understandings of what to do, and what ought to be done. In other words, differences in their knowledge imply the different realities they experience, and therefore, lead to differences in their 'knowledgeability' of what to do, and what ought to be done. It is this acknowledgement of the practice-based approach that enables the inclusion of complexity and variety in the study of organising interdisciplinary design work.

Once the complexity and variety are embraced through such formulation, it becomes exposed that organising interdisciplinary design work is not simple addition of different discipline-specific parts of design developed by isolated expert professionals. Consequently, adopting a practice-based approach problematises the 'working together' of different professionals, and gives a new research orientation that leans towards understanding the role of the joint experiences in the co-production of the 'knowledgeability' of working together. The focus shifts away from focusing on the 'content' of the interactions to the 'effects' of the interactions on what people do and how. In other words, this view sees the interdisciplinary practices as beyond information exchange platforms that merely satisfy certain well-defined information needs. The practice-based view sees the interdisciplinary interactions in design in construction as a joint capacity building arena where the stock of the past is taken in and used to produce the future together for enabling progress. In this respect, the findings of this research show that, practice-based views of knowing and organising explain the connections between the discipline-specific and interdisciplinary, the individual and the team, and thus, give substance to the certainly felt but hard-to-articulate, abstract, organisational concepts and notions such as 'interdisciplinary' and 'team'. For example, Event EE 2 (see Section 4.3.2) shows that at that point in time, the design team did

[6] This refers to the concepts that are used as generic terms without critical conceptual analysis of what they involve. One example of this is the concept of 'information technology' (see for example Orlikowski and Iacono 2001). The ones that are tackled in the present research are 'design (in construction)', 'design collaboration (in construction)', 'ICT (in design in construction)'.

not need any effort to coordinate the M&E services in any room except the ones at the corners of the floors. Their past interactions built a 'knowledgeability' of what to do, and what ought to be done for the design of the M&E services in rooms. However, the exceptional circumstances of the corner rooms required the members of the design team to re-establish a shared sense of purposefulness (i.e. knowledgeability) as discussed in Section 4.4. Event EE 1 (see Section 4.3.2) shows another similar example.

Second, following from the previous point, a practice-based approach reveals the inadequacy of understanding organisation of design work solely focusing on its tangible elements without acknowledging the mundane activities that enable the conditions of their uses at the first place. The three explanatory concepts developed at the end of the Chapters 4, 5 and 6 encapsulate some of the mundane processes that make the interdisciplinary design work possible by looking at the 'doings and sayings' in interdisciplinary design development meetings, engagements with design artefacts, and engagements with integrated computer systems. These explanatory concepts show that professional and institutional standards of practices, legislations, document templates, and other materially-fixed elements of design work, were all subject to re-confirmation, adjustment or sometimes even to re-invention to be used in the performance of the work. All the events presented in Chapters 4, 5, and 6 provide concrete examples of these processes. For example, Event OE 1 shows how a curtain wall system, which is a very conventional application for commercial buildings, was extensively discussed so that an agreement on how it needed to be designed in the particular case of the OffiBuild project was achieved. Therefore, according to the findings of this study, organising interdisciplinary design in construction is about continuous co-production of a definition of the work, its objects and procedures so that their 'knowledgeability' are continuously re-enabled for various practitioners in consistent and coherent ways. This also implies that 'design work' in the minds of practitioners is always more comprehensive than the tangible design outputs because the members of design teams consider all the enabling activities essential to organising; not only the tangible design outputs.

Third, in line with the previous point, the practice-based view allows giving voice to various constituents of the practice of interdisciplinary design in construction through its focus on interactions of a multiplicity of actors and objects by emphasising the critical role of mundane activities in organising[7] (e.g. see Section 5.2). This highlights the fact that interdisciplinary design work is not only accomplished through certain key decisions and technological interoperability, and gives the well-deserved credit to all unfolding face-to-face and remote interactions of the members of a design team which enable the more visible decisions and transactions. This research provides empirical evidence to substantiate this argument, and thus, reveals how this unfolding works in practice, and the underlying efforts that enable more-visible decisions and achievements in projects. For example, Event LE 1 shows how the successful design of the special clean rooms in the laboratory depended on the extra efforts of the M&E sub-contractor because the services in these rooms did not conform to the general design strategy of the M&E sub-contractor.

Fourth, such exposure of diversity also gives an opportunity to include the non-smooth nature of practices in which there are conflicts and power issues that need to be dealt with as part of 'design work' (e.g. Event EE 3). Consequently, a practice-based view of organising also opens up space for the consideration of competing realities that co-exist and interact in interdisciplinary design, and thus, provides a basis to critically question how these are settled in practice.

Finally, this research has showed that these strengths can be amplified by a reflective approach to research methodology. It has been shown in Section 2.2.3 that previously conducted practice-based research on interdisciplinary team work had single empirical focus and built their arguments on single overarching explanatory narratives (e.g. Majchrzak et al. 2012; Bruns 2013). In their narratives, these studies implicitly or explicitly set a number of dimensions of knowing-in-practice (see Table 2 in Section 2.2.2 – Chapter 2) as their pivot to study the empirical phenomena, and theorise about organising interdisciplinary team work through the exploitation of the methodological strengths listed above.

The present research takes a different route in its practice-based approach. In order to develop an appreciation of the nature and process of the change fuelled by technologies of BIM, this research inquired into the activities of organising with the purpose of revealing how order is accomplished in the observed projects, and the role of BIM technologies in this. The practice-based inquiry of the researcher was a journey in which his frame of inquiry

[7] A methodological caution is required in this: delivering detailed descriptions of practices are not objective or neutral. Rather, practices are infinitely rich to study. This means that they can be studied and told from an infinite number of different perspectives, with each story foregrounding certain aspects of the practice (e.g. Suchman 2007). Therefore, selection of a focus on certain aspects of the practice involves a subjective decision in revealing certain subject-object positions in certain ways.

shifted also shifting his attention to different aspects of organising. This research shows that the methodological possibility of foregrounding different aspects, and levels of organisational phenomena in the same study can be fruitfully used to reflect this progressive exploration which is based on the researcher's evolving understanding. Besides, in this case, the different organisational explanations and concepts are outcomes of a continuous empirical exploration, and therefore they are informed by each other and enable nuanced understandings of the main phenomena of interest. For the present research, this means that the concepts of 'organisational premises', 'purposeful artefact', and 'technological premises' developed in Chapters 4, 5, and 6 provide different but equally valid practice-based explanations of organising, thus enabling a rich conceptual base for discussing the accomplishment of 'order'.

7.2.2. 'Order' in BIM-enabled interdisciplinary design projects in construction

From a practice-based perspective, organisational order corresponds to the patterns of activities that can be observed at higher levels (i.e. more abstract) of organisation but are rooted, and continuously re-produced in everyday practices (Schatzki 2001; Feldman & Orlikowski 2011; Nicolini 2012). Drawing on this view, this section discusses 'order' in BIM-enabled interdisciplinary design projects by looking at how and why practices unfold in certain ways, resulting in the establishment, adjustment, or sustainment of certain organisational patterns.

The findings of this study show that 'order' in interdisciplinary design development is an outcome of many evolving, simultaneously influencing, and often competing considerations that are settled through interdisciplinary interactions. Consequently, the understanding of 'order' in interdisciplinary design development that comes out of this study is one that is in constant flux, and that needs to be continuously accomplished through interdisciplinary interactions for adjusting purposes (Chapter 4), and giving purpose to design artefacts (Chapter 5). This understanding of 'order' implies that it is temporary, precarious, and its accomplishment involves compromises, conflicts, negotiations and opportunistic behaviour (e.g. Events EE 3 and EE 4).

However, the concepts of 'organisational premises' and 'purposeful artefact' expose the consistency in settling various design development-related considerations which is based upon an aggregative and path-dependent understanding. This is because practitioners take stock of individual and shared past experiences (and material objects), and use them in producing a future state. Therefore, although 'order' is temporary, and continuously accomplished in interdisciplinary design development in construction, there is also a developing pattern of settling various considerations related to developing the design. This corresponds to 'the (resulting) order' of design development. It is important to identify 'the order', because it is 'the order' that determines the possibilities and impossibilities in design development, and thus, needs to be critically approached.

Chapter 4 shows that it is fundamental for the members of design teams to achieve a shared sense of purposefulness about a design issue for proceeding with their job. Nevertheless, this does not imply that the process of achieving a shared sense of purposefulness is necessarily democratic or equal. Rather, achieving a shared sense of purposefulness only points to a temporary sense of agreement of the interacting parties on what their role would be in tackling the issue. Therefore, the achieved shared sense of purposefulness might not be the ideal or optimum for everyone but is acceptable for the time being. The presence of a variety of purposes based on incommensurate perspectives of various practitioners from different disciplines implies that the discussion that takes place is a negotiation in the sense that practitioners judge how much is expected from them and whether they are willing or ready to do that. In this respect, these discussions can be argued to be political as they involve pay-offs and compromises that have real consequences for the practitioners in terms of the efforts they put in design work. The perceptions and judgements in these interdisciplinary negotiations are based on the organisational premises that represent 'the order' in settling the clashing or conflicting discipline-specific views on design development.

Chapter 5 shows that the shared sense of purposefulness gives sense to design artefacts. The chapter also shows how design artefacts enact further situations and issues through their production, validation, and use; and thus, driving the progression of the design following a certain direction. Consequently, it can be argued that there is a mutual relationship between the development of organisational premises and the production, validation and use of purposeful design artefacts. In other words, there is a mutual shaping between the organisational premises and purposeful artefacts. This mutual relationship can be reinforcing or disruptive, and thus, resulting either in re-confirmation or further negotiations of shared sense of purposefulness and specification of corresponding purposeful artefacts. This then implies that design artefacts can be seen as the materialised forms of the political struggles and power positions stemming from various discipline-specific purposes. As a result, it can be argued that purposeful design artefacts are indeed carrying the power positions among the parties and along the design process, and thus, at the same time both reinforcing them through material fixity, but also exposing them materially to be challenged. Ultimately, the cycle of discussing a design issue, trying to solve it through design artefacts and having further discussions can be seen as an ongoing political process in which various purposes are negotiated both discursively and materially. The 'order' represented through the concept of organisational premises can be argued to stand upon continuously produced, re-confirmed, adjusted or challenged power positions manifesting as discipline-specific purposes and specified aspects of design artefacts.

On the other hand, Chapter 6 shows that technological considerations of model-based working are not always malleable to the needs of design development, and thus challenge 'the order of design development'. Therefore 'the order of the project' becomes determined by not only the design development related considerations but also by technology related considerations. This is because working with technologies of BIM requires strictly following the rigid technological structures and modelling conventions. Therefore, in this situation, the continuous accomplishment of 'order' through interactions does not only involve settling of various considerations around design development, but also the settling of clashing or conflicting needs of model development.

Although the findings show that the modelling conventions and activities are continuously re-negotiated in consideration with their suitability for the changing needs of design work, there were limits to this as what was technologically fixed could be tailored only to a limited extent. In this regard, the technological structures are significant factors in determining 'the order of the project', thus affecting 'the order of design development'. More importantly, the effect of integrated computer systems on the accomplishment of 'order' is unique because of the fixity and rigidity of these systems. The practitioners do not have access to the internal working of these complex digital systems and therefore they are limited regarding the extent they can negotiate the effects of working 'in' the model on 'the order of the project'. Therefore, the position of the integrated computer systems in continuous negotiations of 'order' are fixed, and cannot be stretched. There is no compromise or 'acceptable for the time being' type of solutions for the integrated computer systems.

As a result, there are two major points that this study elicits in terms of the effects of the integrated computer systems on the politics of the accomplishment of 'order' in interdisciplinary design projects in construction. First, it can be argued that these systems impose an ordering effect originating beyond the internal dynamics of the project. The position of the integrated computer systems in the negotiation of 'order' in the project is fixed outside the project to a significant extent, and it is neither accessible nor questionable by the practitioners in the project who need to deal with it. Second, as the integrated computer systems become the main sources of producing design artefacts they also become an instrument of power and control that actors from different disciplines might use to enforce their power positions. In other words, when the fixity of the technology is opportunistically used by a practitioner in the process of achieving a shared sense of purposefulness, or specifying a purposeful artefact, the practitioner can reinforce his/her own position relying on the fixity of the technology which cannot be argued against. Ultimately, this highlights that first, the integrated computer systems in BIM-enabled projects can both carry ordering effects in the projects from outside and affect the ways things are done without being subject to any negotiation. Second, the rigidity of the integrated computer system can be exploited as an instrument of power and control by the actors within the project.

7.3. Adjusting the Constructs with the Realities of Practice

7.3.1. Interdisciplinary design in construction

Section 2.3.2 revealed that design in construction, which is inherently interdisciplinary in practice, is currently under-theorised, and the understandings of design in construction are mainly articulated through distinct design disciplines. As a response, in this section, the construct of 'interdisciplinary design in construction' is discussed based upon the practice-based understanding developed in this study. The section starts with establishing a general practice-based definition of interdisciplinary design to inform the wider design studies. This involves a brief discussion of this new definition in relation to other views on the nature and process of design provided in Section 2.3.1. The section then discusses the problematic nature of practice-based view of interdisciplinary design, the methodological difficulty of researching it, and the particular approach adopted in this study. This provides the vocabulary to articulate a practice-based view of interdisciplinary design in construction. The view established in this study reveals that the current major debate upon which the understanding of design in construction stands do not reflect the realities of practicing interdisciplinary design in construction.

A discussion on the nature and process of interdisciplinary design needs to provide an explanation of how the variety of meanings attached to the same design are worked out so that various discipline-specific parts of design are consistent and coherent with each other. The practice-based understanding that comes out of this study suggests that interdisciplinary design can be defined as '*ongoing organisation of meanings attached to the design work*'. Although this looks trivial, it enables a completely different perspective to understanding design in comparison to other views provided in Section 2.3.1. This practice-based definition of design does not give priority to process, product, or designer. Rather the priority is given to the meanings which are organised in certain ways as a joint result of design product, design artefacts, design process and designers altogether. The definition provided above suggests that interdisciplinary design can be understood through an examination of how design artefacts, product, process, and designers are entangled in practice configuring each other rather than emphasising a definition of design that is based on its differentiation in its artefacts, processes, products, or actors.

This definition of interdisciplinary design, developed in the context of construction, has also the potential to inform the wider debate about the nature of design. It is in line with and provides explanations for the claims that design is a wicked problem (Rittel & Weber 1973), a social process (Bucciarelli 1994), a distributed phenomenon (Busby 2001), and should be studied as culture (Julier 2006), pragmatically (Dalsgaard 2014) or as liberal arts (Buchanan 1992). Such definition also has the potential to better evaluate the previous major conceptions of design. For example, a focus on the ongoing organisation of meanings to understand the design would give substance to Simon's (1999/1969) view of 'bounded rationality' thus extending his definition of design as the science of artificial. Similarly, it would allow to critically understand Yoo's (2012; 2013) insight about the changing definition of design due to the generativity of contemporary ICT. For example, in this case, an emphasis on the ongoing organisation of meanings would suggest that the perceptions on the legitimacy and accountability of the generative technologies are key to understand this emerging definition of design.

Nevertheless, although a focus on 'meanings' provides a fruitful starting point to look at design and its constituents from fresh perspectives, there are difficulties in researching ' organisation of meanings'. The difficulty of researching meanings is that they are abstract, subjective, inaccessible to others and in constant flux. Therefore, to study design as the ongoing organisation of meanings, one needs to make a methodological assumption that enables research inquiry. In this study, this has been the practice-based assumption that "*for those who are involved in it, the accomplishment of a practice is experienced as being governed by a drive that is based on both the sense of what to do and what ought to be done*" (Nicolini 2012: 224). In this respect, the notion of 'purpose' is largely used to establish an account of meaning making in interdisciplinary design development in practice. Formulation of interdisciplinary design work about the notion of 'purpose' is argued to be an important contribution of this study as it captures many subtleties about the nature and process of the practice of interdisciplinary design in construction.

First, working with the notion of 'design purpose' enables the articulation of the variety of individual knowledge, foci, backgrounds, experiences, agendas, and intentions present in design practices. At the same time, setting the level of 'design purposes' as the locus of interdisciplinary interactions in design in construction provides a new explanation for the possibility of both i) autonomy of discipline-specific work; and ii) the consistence and coherence achieved in interdisciplinary design. In this practice-based explanation, discipline-specific purposes drive the works in each discipline, but they are subject to change through the ongoing interactions held with others in the face of evolving situations. This novel formulisation of in-discipline/interdisciplinary design reveals that the main stream framing of it, which is based on the 'fragmentation/integration' debate (see Section 2.3.2) does not reflect the realities of practice.

The findings of this study suggest that the notion of 'integration' (e.g. Oh et al. 2015) is inadequate in capturing the practice of interdisciplinary design in construction. This is because in the studied projects, the parties remained autonomous to a significant extent (i.e. with the exception of technological interoperability which caused clashes between model development and design development). It was not 'integration' in the sense of becoming one, but was rather a 'shared sense of purposefulness' which enabled consistent intelligibility of what to do in design situations for various members of the design team. Therefore, the explanation here is different than previous research that claimed, for example, it is the 'shared understanding' among various members of the team that enables interdisciplinary design (Kleinsmann et al. 2010). From the practice-based point of view, meanings and experiences are unique and cannot be shared. It is argued that this explanation provides a more-articulate position in the 'fragmentation-integration' debate by rejecting any kind of 'integration' among the members of the design team at all. The focus then shifts to 'purposes' implying both practical and managerial consequences that are obscured in traditional 'fragmentation-integration' debate such as facilitation, governance and leadership (instead of structural, contractual integration, and formal - i.e. reductionist – management).

Consequently, focusing on 'design purposes' as the locus of interdisciplinary interactions also implies the inherent political and pragmatic aspects of interdisciplinary work by revealing the multiplicity of the intentions, positions and agendas. Different purposes of different stakeholders that are established as responses to the particularities of the project can be in conflict or in-line to differing degrees. Therefore, interdisciplinary design work becomes a process where purposes and corresponding meanings of the stakeholders are developed, negotiated, tested, abandoned and further developed through compromise, conflict and consensus between different stakeholders. In the previous section, it has been discussed how ‘order’ in design work is accomplished through the settling of various considerations. Together with the use of the notion of ‘design purposes’, understanding of the construct of ‘design as contested’ becomes enabled. These insights into ‘interdisciplinary design in construction’ reveal that it would be beneficial to develop conceptualisations of interdisciplinary design that opens up space to articulate the differences in design team not as something to suppress but to manage.

This practice-based view of interdisciplinary design in construction has also implications for the promoted benefits of BIM technologies. One of the promoted advantages of BIM in construction design has been its capabilities of ‘integrating’ stakeholders, which underpins the view that BIM improves and facilitates stakeholder management in construction design. This argument also triggers the view that more stakeholders should be involved more actively in design through the use of BIM technologies (e.g. Bryde et al. 2013). This includes, but is not limited to early involvement of client, contractor, users and facilities management teams in design (e.g. Porwal & Hewage 2013). However, according to the practice-based understanding developed in this research the fragmentation of stakeholders can be conceptualised as a multiplicity of ‘purposes’. This suggests that various stakeholders of a design project can be understood in the same way: as agents driven by purposes, agendas, intentions and power. Therefore, according to the view of design in construction emerging from this research, involvement of an increased number of stakeholders in design corresponds to an increased multiplicity of purposes, and changing power positions which can have significant implications on interdisciplinary organisation of design in construction. This research shows that standards of practices and individual professional experiences are the basis of interactions of members of the design team in negotiating ‘order’, and therefore they are crucial in enabling development of design through a temporary team. Participation of inexperienced stakeholders in the design team or their early involvement in design imply not only an explosion of purposes that need to be adjusted but also the lack of common interactional repertoires through which different purposes could be negotiated and prioritised. Therefore, the projects that aim for the involvement of more stakeholders at previously untried stages of design must acknowledge this aspect and be ready to face the difficulties of the lack of a common interactional repertoire which is required to achieve a shared sense of purposefulness.

Finally, a reflection on the notion of 'concurrent engineering' based on the definition of design that emerges from this study is useful as BIM is also promoted as enabling the concurrent design of various design stakeholders (e.g. Lee et al. 2012). Establishing an inextricable relationship between discipline-specific and interdisciplinary work as explained in the present study reveals that the notion of concurrent design in construction needs to be approached very cautiously. It has been shown in Chapters 4 and 5 that making sense of 'what to do' and 'what ought to be done' in design relies on a jointly developed and shared sense of purposefulness. Furthermore, Chapter 5 particularly showed that all design artefacts are 'purposeful' in the sense that they are given purpose through interdisciplinary efforts in order to be meaningful, useful and usable. Consequently, it can be argued that an understanding of concurrent engineering based only on the technologically-enhanced accessibility of representations of discipline-specific parts of design is far from capturing the practicalities of designing, and thus needs to be approached cautiously.

7.3.2. Interdisciplinary design collaboration in construction

This section discusses interdisciplinary design collaboration in construction in order to provide a practice-based understanding of it. Drawing on the practice-based definition of interdisciplinary design (see the previous section), this section proposes a practice-based definition of 'interdisciplinary design collaboration in construction'. The understanding of interdisciplinary design collaboration presented in this section clarifies the difference between interdisciplinary interactions, and interdisciplinary collaboration, thus, providing an explanation of its unquantifiable nature.

The literature on the practice-based studies of interdisciplinary team work (see Section 2.2.3) shows that the accomplishment of interdisciplinary team work relies on the interactions that make the practices 'knowledgeable' for various practitioners. This is because generally the practitioners in interdisciplinary teams have different skills and purposes, they come together for a limited period of time, and therefore, the situations they face frequently involve unique aspects that need to be made sense of to take action. This implies that any interdisciplinary team work requires some sort of interdisciplinary effort to create 'knowledgeability' about the ongoing practices. This raises the question whether interdisciplinary collaboration is different than interdisciplinary work.

Setting 'design purposes' as the locus of interdisciplinary interactions provides an explanation for this in the context of interdisciplinary design work. According to the argument put forward in this thesis, what differentiates interdisciplinary design collaboration from interdisciplinary design work is the extent to which the shared sense of purposefulness is achieved among the parties. Consequently, this gives a definition of interdisciplinary design collaboration as '*the purposeful organisation of meanings attached to the design work*'. Such definition of interdisciplinary design collaboration implies that a collaborative design practice is the one where different design purposes are jointly and coherently established and satisfied. This implies a differentiation between the notions of 'interdisciplinary interactions' and 'interdisciplinary design collaboration'. According to the developed definition, even when a project is undertaken in an environment where collaboration is lacking, the interdisciplinary interactions are still in place and essential for establishing design purposes, meanings and design artefacts. However, in a non-collaborative environment, interdisciplinary interactions can be badly affected by the adverse or distant relationships between the disciplines, resulting in incoherent and disconnected purposes that lead to problematic design artefacts. In such cases the problematic artefacts that result from the lack of collaboration would further complicate the joint and coherent alignment of the purposes and lead to even more problematic situations.

On the other hand, definition of design collaboration as purposeful organisation of meanings, highlights the jointly- and coherently-developed sense of purposefulness in such cases. The findings and analyses suggest that in construction design projects, the discipline-specific work and interdisciplinary interactions are inseparable and complementary. However, the effort of jointly establishing and sustaining an understanding of purposefulness can be realised to varying extents. In this sense, the concept of collaboration proposed here cannot be evaluated through neat definitions based on observable factors, or in a binary scale but on a continuum. Consequently, in this conceptualisation, design collaboration is not merely a desired state of interaction among the members of the design team. Rather, it is about establishing and maintaining a shared conceptual sphere (i.e. premises) within which different design purposes can shape, contribute to, flow into, exploit and build upon each other in consistent and coherent ways.

Arguing that the locus of interdisciplinary interactions is 'purposes' also contributes to the wider body of literature around interdisciplinary team work presented in Section 2.2.3. This is because it sets the interface between discipline-specific and interdisciplinary work in a different way than conceptualising them around boundary work (or boundary crossing) (Yanow 2004), trading zone (Kellogg et al. 2006), or detaching the problem from disciplinary fields (Klein 2008) and moving into the 'in-between' fields where they sit in the middle, creating the shared context (Uusitalo 2015). One thing in common in these previous conceptualisations is their focus on knowledge and how different ways of 'knowing' brought by practitioners from multiple disciplines amalgamate in the situated practice. Yanow (2004) puts the emphasis on the discipline-specific ways of knowing, whereas Uuusitalo (2015) claims that this 'in-between' way of knowing resulted through interdisciplinary practices is the central mode of knowing among various practitioners in interdisciplinary work. A 'spatial metaphor of knowledge' though unavoidably refers to various kinds of knowledge that interact in different knowledge spaces such as discipline-specific and interdisciplinary. On the other hand, setting the 'purpose' as the necessary condition of knowing, preserves the unity of knowledge (as required by practice-based view of knowing), and provides a novel way of conceptualising the knowing-in-practice of interdisciplinary practices.

Finally, the practice-based view of interdisciplinary design collaboration put forward in this section implies that reductionist approaches that study collaboration with a focus on the exchange of design objects do not reflect the realities of practice. As shown in Chapter 5, and implied in the practice-based definition proposed in this section, interdisciplinary design collaboration is about achieving a shared sense of purposefulness. It is only through this achievement that any design objects can be given sense, and used for collaboration. Otherwise, mere exchange of design objects cannot be seen as collaborative acts.

7.3.3. ICT use in interdisciplinary design in construction

The practice-based view of organising adopted in this research exposed that BIM technologies are not neutral facilitators of design work, but rather shape and get shaped by wider organisational concerns of projects. The mutual shaping of ICT and organisations is an increasingly presented argument in the studies of technology in organising; for example, around the concepts of materiality of ICT (e.g. Leonardi 2010), and sociomateriality (e.g. Orlikowski 2007). The present research contributes to the understanding of the mutual shaping of BIM and interdisciplinary design practices in construction through the empirical evidence and conceptual developments it provides.

Chapter 6 shows that making sense of interdisciplinary working in digitally integrated computer systems (interoperable ICT henceforth) relies on establishing and maintaining a shared epistemological position (i.e. technological premises) around interoperable ICT. Nevertheless, technological premises are largely influenced by the operational characteristics of ICT which are fundamentally different from the human ones. ICT operations rely on rigid structures developed elsewhere (i.e. outside of projects) and ICT can only perform planned actions (Suchman 2007). Consequently, interoperability of ICT implies that those who contribute to and use interoperable ICT need to strictly respect the inaccessible and embedded structures of it as well as to develop joint plans so that the technology can support their operations. Previous discussions about design and design collaboration revealed that design is a 'wicked problem' (Rittel & Webber 1973) which requires the meaning to be continuously accomplished, and the definition of design is continuously re-articulated in the process of its development. This poses a contrast with the fundamentally structured and planned nature of ICT operations. Therefore, in the projects that were studied in this study, it was observed that technological premises involved an understanding of the limits of model-based working in terms of its accountability, legitimacy and use. This can be argued to be one of the main reasons about the unrealised benefits of BIM (Brewer & Gajendran 2012), the struggle in defining BIM in the construction industry (NBS 2016), and the lower than expected BIM uptake rates (NBS 2016). Consequently, arguments about using the 'full capacity' of BIM needs to be approached cautiously because using interoperable technologies at 'full capacity' implies that everything is regulated, controlled, planned and contingencies are made unlikely. Whether such environments are possible or wanted in design, construction or operations of the built environment remains as a further question that needs to be addressed.

Consequently, it can be argued that, in practice, there are divergent views of 'work' and 'organising' due to the divergent requirements of design development and model development. This divergence becomes more problematic with the increasing amount of integration among various technologies used by various people and practices, and the mandate to stick to them. The EduBuild project had the most ambitious BIM use and the parties were contractually enforced to stick to the 'BIM way of working' (see Section 6.2.3) to a large extent. As a result, it exhibited an overall organisation in which there were purely modelling focused roles, meetings, vocabulary, as well as tensions between the requirements of model development and design development. Similarly, when the client team in the LabBuild project required a model that was coordinated in a very detailed way, this required many additional meetings and raised interdisciplinary issues that had effects on the processes of design development. The concepts of organisational and technological premises developed in this study are useful in capturing this divergence and exposing its extent, and thus, in informing technology development, project management and policy development.

This divergence caused more than simple disagreements that were perceived as part of the usual design work. When the divergent requirements of model and design development implied different necessary courses of actions, the complex mix of diverging requirements puzzled the practitioners making the useful know-how based on learned experiences irrelevant. This implied tensions and confusions in practice (e.g. Events EE 5 and 6). In this new situation, the design team members struggled to make sense of the significances of the conflicting requirements and to articulate what should be coordinated and why? As stated by Jaradat et al. (2013), in such situations it became "*increasingly difficult to rely on institutionalized assumptions about who does what, whose view could override others, and who is responsible for what*". This implied that there is a significant political element of using interoperable ICT in interdisciplinary design.

Looking at the diverging understandings of 'purposefulness' asserted by organisational and technological premises exposes the political dimension of use of ICT in interdisciplinary design. As organisational premises and technological premises are based on different sets of practical concerns as detailed in Chapters 4 and 6, the 'purposefulness' emerging from these two different epistemological positions can differ to varying extents. Although there is an element of 'working with the model' in technological premises that may induce limitations to model-based working in consideration of wider organisational needs of the project, the extent of this is determined by the extent of technological integration and mandate to use the technologies of BIM. Therefore, when technological premises and organisational premises show different directions in terms of what to do, and what ought to be done, this corresponds to a situation that involves politics. The fundamental rigid requirements of interoperable ICT and corresponding perceived advantages as a formal control mechanism (especially by the powerful actors such as the main contractor in the EduBuild project) can leave limited space for its 'appropriation' (Dourish 2003) through negotiations. In this respect, interoperable ICT can be used as an instrument of power and control in the projects disguised as neutral technological requirements.

Moreover, an essential part of technological premises, and therefore the understanding of 'purposefulness' that comes out of it, result from the inaccessible, rigid structures embedded in it elsewhere by technology developers. This implies that working with the rigid requirements of interoperable ICT such as certain file formats, communication protocols and other formal structures appear as certain ways of what to do and what ought to be done in projects. In a similar way, industry or sector wide BIM frameworks, process templates and so on also become part of the technological premises for those who have to operate in them. These two aspects imply that use of interoperable ICT in projects imposes external perspectives on the operations of the projects. In summary, having the 'purposefulness' stemming from technological premises taking over the 'purposefulness' stemming from ‘organisational premises’ imply that technology becomes a source of power and a political instrument that can be used by those who own, manage or have authority on it.

Another important point that comes of the findings and analyses of this research is the limits of digital design data and information models in informing the development of design. In interdisciplinary design projects, the informational value of design artefacts relies upon their symbolic and material aspects. As shown in Chapter 5, these aspects need to be adjusted among various practitioners for enabling their usability, usefulness and suitability for unique situational needs. The findings suggest that in terms of model-based working this can be partly achieved through rules, standards and regulations such as contract clauses, responsibility matrices, BIM protocols and so forth. These instruments provide a degree of shared understanding on the collaborative use of the ICT system, and therefore put some of the automated and human-driven digital data operations into perspective. The constructs that these documents employ, and the procedures that they describe, enable different members of design teams to have a common sense of the technological constructs and the way ICT can/should work. As a result, members of the design team become enabled to communicate about the digital data operations and how they can/should collectively work with digital data and ICT. At an industrial level, the high level of standardisation of technological vocabularies, software development methods, work processes, data formats as well as detailed guidance on ICT mediated work can be all connected to this phenomenon. These instruments aim to provide a common frame for working with digital data in order to enable meaningful multi-party work with ICT. However, no matter how detailed the available documentation and guidance are, and how strictly the regulatory type controls are applied, in design work, there is always a considerable amount of unknowns due to the evolving needs of design. The notion of technological premises captures the ongoing social effort in rendering ICT-mediated data and interactions meaningful in the face of changing needs of a design project. Thus, providing an additional project specific epistemological orientation on top of the general common frame of model-based working provided by the instruments mentioned above.

However, there are many times that this is still not enough to use the information models as purposeful artefacts because as shown in Chapter 5, a purposeful artefact also needs to be tailored according to the particular needs of unique design issues and situations by practitioners. Model-based working has two main shortcomings in these terms. The automated operations made in the models due to software procedures or parametric connections are performed without the knowledge of the practitioners and therefore both miss the chance to increase the meaningfulness and create potential problems for meaning making. Therefore, automation without reflection decreases the information value of the models. Second, information models are representational wholes, which are not malleable to be partly given purpose as response to evolving design issues and situations. Therefore, the argument that having all the representations of design in a single shared digital repository is indeed posing a contrast to how practitioners work with design artefacts in order to make sense of what to do and what ought to be done in design development. Furthermore, the rule-based parametric connections and limited malleability of ICT procedures indeed do not always let the practitioners give purpose to bits and parts of the information models according to the evolving needs and particularities of the projects or situations. Consequently, in all of the observed projects, communications about the development of design were held through the published design artefacts. Even when the models were shown in interdisciplinary meetings, practitioners needed to discuss what to look at in the model, the modelling assumptions embedded in what they see and so on. This corresponds to a significant difference between 'design artefacts' and 'information models', as well as between 'digital design data' and 'design information' that need to be considered in the practices of BIM-enabled interdisciplinary design projects. Therefore, the value of digital design data needs to be considered through its informational value which can only be established through interdisciplinary interactions about specific issues and situations. This point needs to be considered as the most fundamental in model, data and information management in BIM-enabled interdisciplinary design projects.

7.4. ICT-Driven Change in Construction Design

This research shows that the 'digital revolution' in construction design is neither only about technology, nor is it an absolute better way of designing. The findings and analyses suggest that, the so called 'digital revolution' indeed implies a different way of doing things, and hence, it should be subject to critical examination. Previous empirical research on BIM and organising has already reported a number of changes and challenges stemming from the use of interoperable ICT in construction design (e.g. Harty 2005; 2008; Whyte 2011; Dossick & Neff 2010; 2011; Jaradat et al. 2013). This body of literature exposes the significance of the change that the professions (e.g. Jaradat et al. 2013; Scheer 2014) and practices (e.g. Whyte & Lobo 2010; Harty & Whyte 2009) of design in construction have been undergoing due to the use of interoperable ICT. Accordingly, construction management scholars urged for new and better suited methodological approaches (Harty 2005; Jacobsson & Linderoth 2010), concepts (Harty 2008), and conceptions of technology (Whyte 2013) to better understand the complex relationship between technology and organising in construction design with the purpose of enabling a better informed engagement with the ongoing change. Although these studies have created the awareness about the significance and complexity of the phenomenon, they have not provided an overarching theoretical frame which is capable of providing consistent theoretical explanations of the previous contributions.

This research adds to this body of literature by providing such an overarching theoretical frame for organising design in construction when interoperable ICT are used. The concepts of 'organisational premises' (see Chapter 4), 'purposeful artefact' (see Chapter 5), and 'technological premises' (see Chapter 6) developed in this study are the corner stones of this theoretical frame. In this theoretical frame, the three concepts are related to each other through the notions of 'organising' (see Section 7.2.1) and 'order' (see Section 7.2.2). Overall, the theoretical frame developed herein allows to put previous contributions in this field into a comprehensive theoretical perspective which jointly considers the nature of design development (in construction), the nature of design artefacts (in construction), and the nature of integrated computer systems. Therefore, it enables consistent theoretical explanations of the findings of previous empirical organisational research on BIM and design in construction. This will be discussed below in more detail.

One of the main issues that has been recurrently brought up by previous research in this field has been the importance of 'context' in determining the unfolding of ICT implementation and use (e.g. Harty 2005; 2008; Jacobsson & Linderoth 2010; Hartmann et al. 2012). These studies, which emphasise the importance of the 'context', provide empirical examples and explanations about how and why ICT were (or were not) used in certain ways due to a set of contextual factors which characterise the organisations within which ICT were implemented or used.

The present research provides a theoretical frame that encompasses these findings and explanations through the concepts of 'organisational premises' and 'technological premises' developed herein. On the one hand, the concept of 'organisational premises' encapsulates the entire space of contextual factors which are essential to making sense of what to do and what ought to be done, as they infuse everything that is done and the way that it is done. On the other hand, the concept of 'technological premises' relates this to the rigid structures of ICT, and explains the establishment of particular ways that ICT implementation and use unfold in different organisational settings. The connection of these two concepts through the notion of 'order' provides theoretical depth to the explanations of how and why the overall outcome of ICT use might be similar or different in the variety of settings described by different studies.

Other studies such as Whyte and Lobo (2010), and Dossick and Neff (2010) look at the same issue from the opposite perspective, and rather focus on the organisational changes and challenges that are triggered by the implementation and use of interoperable ICT. These studies, on the one hand emphasise the changing principles of organising (e.g. organisational boundaries, organisational roles, control structures etc.) with the shift of more operations to digital realm, and the struggles of practitioners in the face of this. On the other hand, they also show that the initiation, sustainment, and abandonment of these organisational changes are subject to negotiations among various organisational actors.

The present research provides a theoretical explanation that accounts for the findings of these studies based on the concepts of 'organisational premises' and 'technological premises', which are related to each other through the notion of 'order'. The concept of 'technological premises' implies a meaning of 'purposefulness' that considers the planned and rigid operational characteristics of the ICT-in-use. The match between the meanings of 'purposefulness' suggested by 'organisational premises' and 'technological premises' can be similar or different to varying extents in different organisations. Divergences between the views of 'what to do' and 'what ought to be done' suggested by these two developing premises are subject to negotiations which are path dependent (i.e. seen within the existing 'order') but also opportunities for challenging the *status quo* (i.e. challenging and changing the existing 'order'). Therefore, operationalisation of these two concepts through the notion of 'order' provides a theoretical grasp of the findings of the previous studies about the changing organisational principles due to ICT use.

Another major theme in the previous research on BIM and organising construction design has been about the effectiveness of the use of interoperable ICT systems as interdisciplinary communication tools. When exploring the BIM-enabled projects, this corresponds to inquiring into the effectiveness of the interdisciplinary use of information models in supporting various members of the design team in their jobs (Moum 2010; Neff et al. 2010; Dossick & Neff 2011; 2014; Whyte 2013; Merschbrok & Wahid 2013). These studies show that providing an extended pool of digitally integrated design data, which ideally involves the entirety of the design documentation, cannot be directly linked to the effectiveness of interdisciplinary communication in construction design. They express concerns about the fixity and inflexibility, which could be counter-productive for design development, induced by digital integration due to the planned, rigid and structured nature of information models. Besides, the findings of these studies show the necessity of human-human interaction outside information models (e.g. face-to-face meetings etc.) for enabling effective communication in design teams.

The present research proposes the concept of 'purposeful artefact' to encapsulate the challenges of the interdisciplinary use of information models in construction design articulated by previous research, and therefore enables an overarching theoretical explanation of them. The concept of 'purposeful artefact' suggests that all design artefacts need to be given purpose based on both individual and shared (i.e. by the members of a design team) past experiences through which the particulars of various design situations, communicating parties, and the materiality of the artefacts are established and adjusted. This implies that in highly non-routine working situations, in which the issues that need to be addressed continuously change, such as design development in construction, communication devices need to be malleable to change and transparent in order to be effective. Hence, this overarching theoretical explanation establishes why the inaccessible automated (i.e. opaque) operations and rigid structures of information models pose communication challenges in construction design.

Previous research on BIM and organising also highlighted the amount of *extra* effort necessary to set-up and run interoperable ICT systems (Whyte 2011; 2013) and the implications of this necessity on the meaning of professionalism (Jaradat et al. 2013), and on the limits of ICT-mediated organisational configurations (Whyte et al. 2016).

The present research enables a theoretical explanation also for the findings of these studies by establishing theoretical connections between design artefacts (i.e. the concept of 'purposeful artefact'), wider organisation of design work (i.e. the concept of 'organisational premises'), and the characteristics of technology use in organisations (i.e. the concept of 'technological premises') through the notions of 'organising' and 'order'. According to the theoretical frame developed in this research, it can be argued that the opaque, planned, fixed, and rigid nature of ICT-mediated information models force those who have to work with them to come up with new ways of giving purpose. These correspond to establishing new interactional (i.e. organisational) routines which are eventually more planned and structured to suit the need of giving purpose to these digital artefacts which are significantly different in their nature than the traditionally used ones (i.e. paper and CAD drawings). Therefore, the new interactional routines required to give purpose to digitally integrated artefacts are different than traditionally established interdisciplinary design interactions. The largely separately held model-focused teams, meetings, vocabularies (i.e. talking about object ownerships, object families) that were observed in practice can be seen as the examples of this phenomenon. As a result, this implies the need for novel and different kinds of professional knowledge and organisational settings, thus causing divergent views of organising (i.e. represented in this research by the concepts of 'organisational premises' and 'technological premises') competing for determining the 'order' in a project. Consequently, the present research enables a comprehensive theoretical frame which clearly explains how the difficulties in giving purpose to ICT-mediated artefacts affect the organisation of construction design at various organisational levels as well as the professions of construction design.

Ultimately, the present research bridges between the practice-level and an unprecedented level of abstraction in this body of literature. Therefore, a discussion of ICT-driven change in construction design, which is based on the results of the present study, needs to be provided in order to inform the future trends, and future practical and research efforts in this field. The present research reveals that the use of interoperable ICT in construction design imposes new views of 'working' and 'organising' which are only partly negotiable in local contexts (of everyday practices) and can be exploited as an instrument of power and control to impose certain views of 'working' and 'organising' in the favour of those who have knowledge, access or authority to control the technology. Therefore, the change that has been taking place enacts at the level of 'purposefulness', creating divergent needs of model- and design-development. The current promotional rhetoric concerning BIM largely conceals this divergence, and according to the findings of this study, in practice, this results in the segregation of efforts, activities, and roles in order to satisfy diverging purposes of model-based working and design development.

It can be argued that the industry will eventually develop optimised ways of dealing with this divergence considering both technological and design development requirements in a balanced way (e.g. Whyte 2013 proposes the use of 'open systems' -as a concept- which acknowledges the necessity of human intervention into ICT operations), thus, enabling interoperable ICT-supported enhanced collaboration. However, this cannot be taken for granted considering the rigid and planned nature of the ICT, persistence of the technology-centred rhetoric around digital technologies, and the potential exploitation of interoperable ICT as disguised instruments of power and control. Consequently, an awareness of this divergence and necessary social and technological precautions are required in projects. As part of this, project participants also need to establish which positions are privileged as part of engaging as a professional within the project.

At a larger scale, the digitally integrated way of working explored in this research implies a significant change in institutions and standards of practices such as shifting meaning of professionalism as exposed by Jaradat et al. (2013). This change has been going on without an open discussion of the new meaning of 'purposefulness' emerging through the use of BIM and its rationale. On top of this lack of critical discussion, further digital advancements that promote more integration and data accessibility have continuously been encouraged. The explosion in the amount of data in the built environment due to the increasing use of BIM has triggered the discussions about 'big data', and therefore, further digital integration in the built environment. This research brings out questions about the digital integration at the scale of built environment, and the consequences of this for the inherent variety that it inhabits.

Institutional theorists (e.g. DiMaggio & Powell 1983) claim that organisations that are connected, or similar, to each other through exchange relations and/or communications are subject to socio-economic pressures that drive them towards the norm. DiMaggio & Powell (1983) argue that beyond a certain intensity of interactions between the organisations within an organisational field, the commonalities within the field (e.g. professional roles, organisational structures, policies that should be obeyed and technological infrastructures that should be worked with etc.) do not necessarily reflect the most competitive solution for each organisation within the field but rather reflect the decisions taken by the most visible, powerful and legitimate-looking organisations. This argument was confirmed by Swanson and Ramiller (1997) who study the institutionalisation of information systems innovations, and Fichman (2004) who argued that innovation adoption requires study through non-rationalistic models.

All these imply the need for more-critical examination of the transformation taking place in the built environment against the technology-focused utopian claims. The mediation of interdisciplinary design work by interoperable ICT constitutes a different working situation which involves a novel understanding of purposefulness in interdisciplinary design. Consequently, the discussions around the development and use of interoperable ICT for design in construction need to go beyond the technological and economic arguments. Such discussions must consider the politics at the project level, and aesthetics and ethics at the institutional level. Therefore, use of interoperable ICT in interdisciplinary design projects needs to be regulated by open policy making which considers the effects of ordering of interoperable ICT. In its simplest form then, the main discussion about the 'digital revolution' must be held at 'the level of purposes' in order to accommodate the inherent social and material variety in the built environment, and enable industry-wide positive change through informed technology development and design practices.

CHAPTER 8. CONCLUSION

8.1. Introduction

The global trend of digitalisation in all aspects of life has manifested itself in the construction industry under the umbrella term of 'BIM'. The main thrust behind this trend has been the belief that more data equates to better-informed practices. According to this way of thinking, aspects of all practices could be formulised in terms of data, and improved by using the data-generation and management capabilities unlocked by contemporary ICT. However, such a view has been demonstrated to be reductionist, and not reflecting the complex realities of actual practices. Therefore, although it has been widely accepted that the ever-increasing digitalisation has been transforming the organisational, economic, and social phenomena, the nature and extent of this change have remained obscure both at the global and construction industry scales. This situation is problematic as it implies that people have limited understanding of what they are experiencing, and therefore, have limited chance to intervene to negotiate their needs, desires and positions in it. It is both surprising and worrying that more attention has been paid on technologies than on understanding the experiences of people who have to work with them.

Consequently, the present research took on the challenge of developing a practically relevant conceptualisation of BIM-enabled interdisciplinary design work with the aim of exposing and critically questioning the nature and extent of the ICT-driven change that has been taking place. Unsatisfied with the disputed and abstract constructs of 'design', 'design collaboration', and 'ICT' (in interdisciplinary design), this workplace study inquired into the level of interdisciplinary practices in order to explain how 'organising' and 'order' are accomplished in BIM-enabled interdisciplinary design work. The study of such a complex phenomenon - that involved numerous people, technologies and other materials in constant interaction - required methodological innovations faithful to the fundamental principles of 'practice thinking' adopted in this research. The resulting practice-based research approach has enabled to capture the variety and complexity inherent in the observed practices, and thus provides a novel explanation of interdisciplinary design work in BIM-enabled projects.

This explanation is underpinned by the everyday interactions that generate 'organisation' and 'order', rather than relying on 'black-boxed' constructs that tend to see people as professional stereotypes, things as useful as given, and activities as directed to fixed ends. The understandings of 'organising', and 'order' that emerged from the analyses of this thesis have been striking as some of the main arguments upon which the promotional rhetoric of BIM stands are disproved or shown to be as not straightforward as they seem. Therefore, the novel ways of thinking about 'design', 'design collaboration', 'ICT' (use in interdisciplinary design), and 'ICT-driven change' are discussed in order to reconcile these constructs with the realities of practice. Ultimately, this thesis shed some light on the nature and extent of the ICT-driven change that has been happening with the mission of enabling a novel order of practices in which practitioners and researchers have better understandings and a vocabulary to take part in the debate.

In this final chapter of the thesis, first the reflections upon the achievements (Section 8.2) and limitations (Section 8.3) of the study are presented. Following this, in Section 8.4., the contributions of the research will be summarised as a set of overarching points. The final section of this chapter, Section 8.5., provides some directions for future research.

8.2. Achievements of the Research

In this section, the achievements of the study are presented by placing the results of the study into a wider perspective to better appreciate the significance of the findings that come out of this research. This also supports the readers of this study in their reflections upon the findings, and therefore their use of this study for undertaking further research. The wider frame exposes the unique contribution that a practice-based approach enables by delineating the differences between the 'explanations' and 'doings' of practices, and their consequences.

The organisational concepts developed in this study give profound messages to researchers, practitioners, and technology developers. In a world where everything is getting more and more divided into categories (Star & Bowker 2007) (i.e. this word is deliberately chosen instead of using the word 'specialisations' which has an unsubstantiated positive connotation), and put into computerised operations along these categories, the concepts of 'organisational premises', 'purposeful artefact', and 'technological premises' emphasise the 'unity' that is required for meaningful action in practice. They emphasise that, in practice, there is no integration, no fragmentation, no discipline-specific knowledge bases, no BIM levels, or in summary, no clear cut categories *per se*. Practice is where all these 'categories' and 'labels' come together in certain ways, and become meaningful as a relational whole. The modern way of seeing things is fundamentally based on working with and through categories which are also embedded in the design and development of the technologies. Hence, the ever-increasing categorisation of all aspects of the world becomes further accelerated and deepened through the functioning of the technologies that they are based on, and by working with them. Nevertheless, the categories fall apart when they hit actual *practice*, leaving people and the material world alone to produce some sort of unity in order to be able to make sense and go about their lives. In this respect, this research exposes a different understanding of organisational phenomenon that emerges when the focus in understanding organisations shift from a collage of distinct categories (of people, knowledge, things etc.) to the activity of achieving some sort of meaningful unity in practice.

Therefore, the first major achievement of this research is in its exposition of how the categories that are used in talking about, understanding, and managing practices become mere elements of a larger whole in practice, thus proving the arguments developed on categorical views incomplete or wrong. On the one hand, the three explanatory concepts developed at the end sections of Chapters 4, 5, and 6 show what this means for BIM-enabled interdisciplinary design practices in construction, and thus, unlocking completely different definitions and understandings around interdisciplinary design in construction. For example, the concept of 'purposeful artefact' emphasises that the informational value of a hand sketch can be bigger than a fully detailed information model depending on the agenda of the person using them, and his/her historical relation with them. On the other hand, the practice-based approach adopted in this study opens a path for future similar attempts. Furthermore, this novel way of looking at 'organising' in BIM-enabled interdisciplinary design work raises major critical questions about the current ways the technologies are conceived, designed, marketed, sold, purchased, used and updated for interdisciplinary design in construction. Similarly, this implies a novel way of managing in construction as the meaning of the concept of 'work' becomes grounded in the practice, and therefore a clearer articulation of what needs to be managed and why becomes possible. Consequently, the methodology and concepts of this study opens up a major critical space within which previously employed beliefs, constructs, standards of practices, and any other 'categories' or 'labels' employed around interdisciplinary design work can be discussed through the practice-based understanding of 'organising' that is developed. Sections 7.2, 7.3 and 7.4 of the study have provided examples of such discussions and showed how practically relevant, novel, and counter-intuitive definitions and understandings can be achieved through such an approach.

Besides, and at the same time, categories are needed and they matter as they furnish the structures of making sense of the world. They determine the ways people and materials are configured, and the space of imaginable configurations (Suchman 2007; Mazmanian et al. 2014) (i.e. possibilities of configurations). Therefore, they become the resource for stability for infinitely complex web of practices. In this respect, the categories, and the ways they manifest themselves in practices define the way things are done in practice: the 'order'. It is in this sense that practice-based understandings of ‘organising’ and ‘order’ go hand-in-hand. An explanation of ‘organising’ describes the process of the accomplishment of the unity, or the meaning, which results from a particular configuration of people and materials. On the other hand, an explanation of ‘order’ seeks to describe why things are configured the way they do by looking at the particular ways that the ‘labels’ and ‘categories’ manifest and drive practices. The way things are done, the way they could be done, and the way they could be imagined to be done depend on the available categories and the ways they are confronted in practices. Therefore, developing a practice-based understanding of ‘order’ is as important as understanding ‘organising’ in order to appreciate why the things are the way they are, and to create a sense of what it would take to change them. In this respect, digitalisation of as many aspects of practices as possible gives the technology the power of determining both the categories and the ways these categories manifest in practice. It is in this sense that technology becomes an instrument of power and control that transforms ‘the order’ of practices. Therefore, this research exposes an understanding of ‘order’ that enables critical inquiry and insight into the nature of the ICT-driven change in interdisciplinary design in construction.

The second major achievement of this research is in its exposition of particular ways various categories and labels manifest themselves in BIM-enabled interdisciplinary design practices and drive them in certain ways. This provides clues about where to look at to explore the change, how to understand it, and potentially how to intervene in it. The concepts of ‘organisational premises’ and ‘technological premises’ imply repertoires of categories and their imaginable configurations and manifestations to make sense and take action. Moreover, the concept of ‘purposeful artefact’ implies that the artefact is always directed towards certain ends, it is part of a certain configuration, and therefore it is not self-evident, neutral or objective. Therefore, the conceptual contributions of this research opens up a new horizon to look at, and understand the change in interdisciplinary design in construction from a critical and practically relevant perspective. In other words, the picture of ‘order’ that emerges from this research opens up another major critical space where things looking as ‘neutral’, ‘better’, ‘natural’, or ‘just the way it is’ can be seen from a perspective that exposes ‘the order’ that they sustain, and eventually the beneficiaries of that ‘order’.

Nevertheless, it must be re-emphasised that some sort of order is always needed to make sense of the world, and to be able to follow some courses of action. The real challenge is then to create and maintain spaces for the negotiation of ‘order’ in which different voices that characterise the built environment practices can exist. The current motivation of the digitalisation trend is digitalising all aspects of practices, and thus, giving the total control of the categories and the practical encounters with the categories in the hands of technology. This increasingly decreases the potential spaces of negotiation and resistance that are needed for a change that is driven by the engagement of different voices that are affected by the change. In consideration of this totalitarian approach, the explanations and concepts developed in this study become more important in enabling spaces of negotiation of various voices and their resistance. Consequently, on the one hand, the organisational concepts established in this research reveals 'order' as an enabler of meaning and progression, and thus, enabling an informed ground upon which practitioners and researchers can build up to develop more efficient practices. On the other hand, they also expose the fact that 'a particular order' is not the natural, better, or the only way to do things. Rather, every order brings certain benefits and disadvantages to certain positions, and therefore, must be open to negotiations that consider politics, ethics, aesthetics and economics. This enables not only an explanation and critical discussion of ICT-driven change in design in construction but also lays a fertile ground to further study 'order' in interdisciplinary design work in construction with various other foci. Sections 7.3 and 7.4 involved elements of the view of order that came out of the findings and analyses of this study, and revealed how technology is a disguised instrument of power and control, and how it interacts with other ordering structures in the project.

Ultimately, it can be claimed that this research achieves its research challenge of providing a practically-relevant conceptualisation of BIM-enabled interdisciplinary design in construction. Furthermore, it reaches its aim of developing an understanding of the change in interdisciplinary design in construction that has been fuelled by technologies of BIM by the understandings of 'organising' and 'order' it provides. The methodology, analyses, vocabulary and concepts that it provides enable deep insights about the nature of the ICT-driven change, how it can be made sense of, critically explored, and intervened in. Moreover, the discussions, concepts, and the vocabulary that have come out of this research indeed correspond to new 'labels', 'categories' and possibilities of configurations. Therefore, this research constitutes an important step in enabling a different 'order', in which the social and material variety inherent in the built environment can be better appreciated.

The research exceeds its aim because the explanations and concepts developed in the study can be used beyond a focus on ICT-driven change. As explained above, these explanations and concepts enable valuable insights regarding the overall operation of design practices, and furnish a fertile ground for further original analyses and concept development at different levels of abstraction and in different streams of research in design in construction.

8.3. Limitations of the Research

The methodology adopted in this research implies a number of limitations that need to be acknowledged. The main point about these limitations is that the researcher has been the main research instrument/conduit in this study. Therefore, other people may see the phenomena studied in this research differently. The value of this study is then in its explanation that enables fresh perspectives, and vocabulary to critically look at the same phenomena.

First, the empirical findings are collected from only three projects. Although the concepts developed in this study reflect dynamic processes, and are far from being conclusive in their nature, it is impossible to say whether the concepts and arguments developed in this research would be in line with other BIM-enabled design projects. Second, the data collection mainly relied on field notes and informal communications which were not allowed to be recorded. Although the lack of recorded data has been compensated for through multiple cases, longitudinal data collection, and formal/informal interviews, the inaccessibility to the recordings of the situations needs to be acknowledged as a limitation. On the one hand, in a longitudinal, ethnographic study this is not such a big problem as the conceptualisation is progressive. On the other hand, especially in a longitudinal study, the opportunity of revisiting the past moments through recordings could be rewarding and reveal more nuanced understandings of the unfolding of practices. Third, the way the narratives were written in this study aimed to preserve the frame of inquiry of the researcher, and serve as a structure for the argument that put forward in the thesis. Therefore, it is important to acknowledge that the research presented on the pages of this thesis could be interpreted and written differently. As stated previously, describing and theorising about practice always requires a frame that involves a focus and a particular language. Such frames used in this study were chosen with the consideration of their commensurability (see Section 3.3.2 in Chapter 3) but also according to the researcher's journey, taste, and the argument that he wanted to put forward. Although this 'personal touch' is allowed and even encouraged in ethnography, it remains as a limitation for the generalisability of the study. Fourth, in line with the practice-based approach it adopted, this study focused on activities, and did not consider several unobservable aspects of practices such as the effects of gender differences and age. It is acknowledged that interpersonal feelings would certainly have impacts on how the interdisciplinary work is organised at interactional level. However, the empirical orientation of the practice-based approach on the observable interactions did not allow such considerations.

8.4. Contributions of the Research

In this section, contributions of the research will be summarised under the categories of theoretical, methodological and practical contributions.

Theoretical contributions

In terms of theoretical contributions, first, this research presents a uniquely selected set of literature that enables a critical examination of interdisciplinary design practices in construction. Incorporating research from a large variety of research streams enables further similar studies to better acknowledge their own theoretical position in terms of the ongoing major debates in design studies, organisational studies, and studies of technology in organisations. Furthermore, this research has developed novel practice-based explanations of 'organising' and 'order' in interdisciplinary design in construction through three explanatory organisational concepts. It has been shown that these theoretical developments are useful in developing practically-relevant and critical understandings of higher level constructs and phenomena relevant to BIM-enabled interdisciplinary design in construction. As part of this, theoretical discussions have been held around the constructs of design, design collaboration, ICT (in interdisciplinary design), and the phenomenon of ICT-driven change in design in construction. These discussions revealed many unarticulated aspects about these constructs and phenomenon, and thus, contributing to their theoretical understanding from a practice-based perspective which has been largely missing. As a result of these extended theoretical understandings, it has been shown that the discussions about ICT use and ICT-driven change in interdisciplinary design in construction must consider politics, ethics, aesthetics, and economics.

Additionally, as explained in Section 8.2 the theoretical grounds of 'organising' and 'order' established in this study provide a valuable practice-based ground regarding the overall operation of design practices in construction. Therefore, it can be argued that this research makes a major theoretical contribution by establishing a practice-based theoretical base which can be used in developing critical, and practically relevant understandings of numerous phenomena and constructs relevant to design in construction from various perspectives (e.g. organisational, social, managerial and economic). In this respect, the theory developed in this study can be used as the starting point to develop a number of further practice-based explanations and concepts around interdisciplinary design in construction. This could then be distilled into further refined concepts and used by other fields of research such as technology design and individual design disciplines (e.g. architecture) to adapt those fields into the practical realities of interdisciplinary design in construction.

The theory developed in this study shows that a sensibility on 'order' adds to the theoretical contributions of research. This requires not only investigating empirical phenomena but also a deeper questioning of why the things happen the way they do. This additional dimension of investigation can be particularly useful for theorisation in critical studies that aim to question the taken-for-granted aspects of their phenomena of interest. In particular, the ordering effects of interoperable ICT revealed in this research shows that research that studies technology in practices must consider the technology as a source of power and control rather than a neutral or objective tool.

Methodological contributions

In terms of methodological contributions, this research shows how a practice-based approach can be developed according to the particular organisational phenomenon of interest and the particular difficulties of its description and theorisation. Although this requires a reflective engagement at philosophical, theoretical and empirical levels, the originality of the findings enabled by this approach justifies the extra effort. This study painstakingly goes over its philosophical, theoretical and empirical orientations, and opens a path for further research that may consider developing a research-context-specific practice-based approach. This involves discussions about the issues concerning:

- the composition of a fit-for-purpose analytical 'toolkit' to combine the strengths of various commensurable practice-based theories and methodologies;
- the development of research questions in line with the adopted philosophical assumptions;
- the management of attention during the observation of the practices that are being studied;
- the navigation and associations of different levels of organising through zooming-in and -out to the observed practices;

- the use of language in making sense of as well as writing about practices (including the development of a writing style to allow both messiness and harmony inherent in practices);
- the development of concepts which need to acknowledge both dynamism and stability inherent in the observed practices.

As part of developing its practice-based approach, this study provides a detailed account of the problematic nature of researching and practicing interdisciplinary design in construction in terms of ontology and epistemology. Thus, it makes a particular contribution for the study of interdisciplinary design in construction.

Practical contributions

First of all, this research provides an entirely new way of looking at and talking about design, design collaboration and BIM technologies, and hence enables the legitimisation of everyday, mundane activities as the house of organising and order. In this new perspective, facilitation of achieving to a shared sense of purposefulness is the first and foremost condition for successful design, design collaboration and technology use. This implies that management of design projects, policy development in BIM and technology development must shift their focus from computable information, business processes or content of design communication to the processes of governance, story building, relationship building, and convention building in projects. Although smooth technological interoperability is a necessity to be able to enjoy certain potential benefits of technologies of BIM, it has been shown that these cannot be beneficial unless a joint epistemological position is established and sustained among the parties working together. Moreover, it has been shown that the new understanding of purposefulness that emerges due to the operational requirements of technologies of BIM might be suppressing other understandings of purposefulness in the project which are essential for good design practice. Furthermore, this aspect of technologies of BIM can be exploited as a disguised instrument of power and control by certain positions inside or outside of the project. Therefore, policy making and managerial attention must be directed to eliminate the potential domination of technology-based purposefulness at the cost of other ways of looking at the design developed through learned experiences. Consequently, informed and open policy making and managerial approaches are required for the regulation of the BIM-enabled design in construction in order to identify and eliminate the potential cases of suppression by or exploitation of the rigid ways of working imposed by interoperable ICT.

8.5. Directions for Future Research

This research reveals that more practice-based studies need to be conducted in the face of complex problems of the contemporary world. The problems and challenges that are being experienced in today's world are complex as they involve many different social and material worlds that have consequences on each other. Understanding and resolution of the complex problems through black-boxed and abstract constructs are unlikely because such constructs are unable to capture the ongoing mutual shaping of the interacting entities. Therefore, such solutions risk both erasing the variety inherent in the world of practices and neglecting different responses of different entities to the same practices.

Second, this research suggests that the concepts of 'organising', and 'order' need to be used more to make sense of, describe and explain complex phenomena. As explained in Chapter 3 - Methodology Chapter, it enables making associations between the practice-level activities and the effects that can be observed as higher (i.e. more-abstract) levels of organising such as organisational structures and order. Therefore, practice-based research understands the micro mechanisms that create and deepen these challenges, and thus, is better equipped to address them. As explained in Section 8.2, practice-based research has the potential to open up critical spaces to enable alternative perspectives, understandings and discourses through revealing how various things come together, and why they configure each other the way they do. Therefore, future research needs to pay more attention to the unfolding of practical situations to address profound questions and tackle complex problems. The explanations and concepts provided in this research provide a useful starting point to undertake this mission in the domain of interdisciplinary design in construction. Overall, a further effort in, and refinement of practice-based research is recommended in organisational studies in construction management, and beyond.

Finally, the insight that is gained from this study can be used in developing both new approaches to ICT design and development, and to organisational management. The concepts, ideas, and discussions that come out of this research reveal that novel frames are required in both areas in order to enable more 'practice-friendly' technologies, and management systems.

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APPENDICES

Appendix 1: Preliminary Research - Interview Questions

1) How has BIM implementation changed the roles of practitioners working in design projects?
2) What changed in business (and work) practices with the implementation of BIM?
3) What information is being exchanged with other project participants at which stages of the project?
4) What are the means of these information exchanges?
5) How did information exchange methods change with the implementation of BIM?
6) What is your perception of BIM? A completely new way of doing business or just a technology platform change?
7) What are the major changes (positive, negative and neutral) that have been introduced with implementation of BIM?
8) What are the bottlenecks that prevent BIM to be exploited better (if you identify any)?

Appendix 2: Agenda of a Design Coordination Meeting in the EduBuild Project

[redacted]

[redacted]
Design Coordination Meeting

CONTRACT	[redacted]
CONTRACT NO.	[redacted]
DATE	21.05.14
WEEK NO.	61
TIME	09.30
LOCATION	Site Offices

PRESENT	
[redacted]	
APOLOGIES	
[redacted]	

1.0	**Previous Minutes**	[redacted]
1.01	[redacted] to report details of smoke vent louvres automatic control to [redacted].	
1.02	Further fixing details of the door air curtain to be submitted to [redacted].	
1.03	[redacted] to issue layout drawing of Loading Bay plant with dimensions & weights this week. [redacted] to issue section drawing for pub ventilation ducts, with air volumes and air velocities detailed.	
1.04	Dry store extract now to terminate with wall louvre in the Loading Bay. Louvre location to be marked out on site.	
1.05	Ceiling tile option to be adopted for return air in lieu of linear diffusers. Mock up to be erected in Phase 2 with light fittings for review.	
1.06	M&E matrix to be re-issued this week.	
1.07	[redacted] model for baffles/chilled beams/lighting coordination ongoing. [redacted] to bring 5^{th} Floor co-ordination drawing forward to review Boardroom areas.	
1.08	[redacted] to issue revised vent calculations for the Deli area and Dry Store area to [redacted] for comment	
1.09	[redacted] issued details of the Trench heating to [redacted]	
1.10	[redacted] to update drawings to include Dry Riser pipework route. [redacted] to forward Landing valve detail to [redacted]	
1.11	High level Atrium wall motorised louvre required for ventilation – size & location to be advised by [redacted]	
1.12	[redacted] confirmed having issued initial proposals, prepared by [redacted], for Loading Bay ventilation/noise data to [redacted] for comment.	
1.13	[redacted] have commented on the life safety panel locations.	
1.14	[redacted] to determine the discharge point from the basement sump pump	
1.15	Positions of services within the [redacted] courtyard to be reviewed between [redacted] and [redacted]. Meeting to be arranged to view on site.	
1.16	[redacted] issued details of the 2050 Cooling Load principle to [redacted] for comment.	
1.17	All small power layouts now issued for all floors. [redacted] drawings to be submitted this week and forwarded to [redacted] to review and comment. Future meeting to be arranged w/c 02 June for [redacted] to discuss.	
1.18	Double stacked AHU to be reviewed when [redacted] have issued roof duct layout. All other roof duct layouts to be issued for step over locations.	

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[redacted]

2.0	Architectural Update	
2.01	[redacted] issued all outstanding [redacted] items: <u>Ceilings</u> Lights – these are now in the [redacted] model, however there are a few rooms that require coordination where a different number of light bars have been shown: CCZ163; CCZ271; CCZ272; CCZ366; CCZ404; CCZ417; CCZ455; CCZ457; CCZ458; CCZ462; Lights – Lights to SER and various stores are bulkhead fitting; ceiling is clip in grid. Lights – illuminated baffle lights to ground and first floor atria shown incorrectly as suspended fittings between baffles. Lights - lighting to south block atrium base to be updated with spots as per meeting with [redacted]. Periscopes – confirmation required if ceilings are required to internal small offices for vent routes over. This will impact on lighting type: CCZ409; CCZ412; CCZ415 Chilled Beams – [redacted] had chilled beams to [redacted] and [redacted] – are these still required?: CCZ355; CCZ371 Vent Grills to Bulkhead Soffits and ceilings – Are any required above ground floor, or is perforated tile used throughout? [redacted] Speakers – [redacted] drawings in DWG, including which rooms need additional blank panels in Linea lights Smoke Detectors – I cannot find any drawing locating these, and they are not in the Revit model CCTV Cameras – DWG of [redacted] GA-68100 and 68200 series drawings, with ceiling mounted fitting isolated on a separate layer Duct runs – Confirmation that all ducts are now shown in Revit model Pipe Runs – Confirmation that all pipe runs are now shown in Revit model RWP runs – Confirmation that all RWP runs are now shown in Revit model Cable trays - Confirmation that all cable tray runs are now shown in Revit model Ceiling / soffit mounted WIFI - I cannot find any drawing locating these, and they are not in the Revit model [redacted] Projectors – [redacted] are modelling these from [redacted] drawings [redacted] Screens – [redacted] are modelling these from [redacted] drawings Legacy AV to Court Rooms – confirmation of siting / throw criteria for coordination Any other ceiling / soffit mounted MEP items not listed above – please advise <u>Roof</u> Ductwork – none shown in Revit model Plant support framework – none shown in Revit model Lights – these are shown floating – assume connected to the above! Pipe Runs – Confirmation that all pipe runs are now shown in Revit model Cable trays - Confirmation that all cable tray runs are now shown in Revit model [redacted] to review [redacted] comments and reply to all points.	[redacted]

[redacted]

Design Coordination Meeting

[redacted]

2.02	[redacted] issued door schedules for Laminates.	Note
2.03	Flue detail issued to [redacted]. [redacted] queried waterproofing detail to support & Flues.	[redacted]
2.04	Ventilation slot through timber stair treads to be finalised. [redacted] to review requirements.	[redacted]
2.05	[redacted] roof/glazed corridor roof junction north wing gutter detail to be finalised.	[redacted]

3.0	**Structural Update**	
3.01	No report issued.	[redacted]

4.0	**Mechanical and Electrical Update**	
4.01	[redacted] to update schematics after M&E workshop to incorporate [redacted] comments.	[redacted]
4.02	[redacted] to comment on [redacted] External Lighting calculations.	
4.03	Meeting to be arranged with [redacted] to discuss fixing details for external lights	
4.04	Make-up air facility for smoke ventilation to be reviewed.	
4.05	[redacted] requested details for socket outlets/data, wall or ceiling for Retail Units.	

5.0	**Any Other Business**	
5.01	Next meeting to take place 04 June 2014.	[redacted]

Appendix 3: Papers Published During the Research

PAPER 1

Citation: Çıdık, M. S., Boyd, D. and Thurairajah, N. (2013). Understanding the polarized perspectives in BIM enabled projects. In: Smith, S. D. and Ahiaga-Dagbui, D. D. (eds), *Proceedings of the 29th annual ARCOM conference*, 2-4 September 2013, Reading, UK, Association of Researchers in Construction Management, 703-713.

UNDERSTANDING THE POLARIZED PERSPECTIVES IN BIM ENABLED PROJECTS

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ABSTRACT

Successful implementation and use of Building Information Modelling (BIM) require consideration of people issues. Two polarised views of BIM are shown from the literature based on technology-centred or human-centred perspectives each of which acknowledges the other but subsumes this into their view. Indeed it is the way that each adopts the other that is problematic. This paper demonstrates that acknowledging these differences and working with them better addresses the management of the implementation of BIM. Empirical findings, from in-depth interviews in a multi-disciplinary engineering company, show that individuals use BIM but are confused by its role depending on their job and perspective. Given this, collaboration and development are held back by the un-expressed differences. It is argued that recognising these differences and using them in a balanced way is essential for the successful adoption of BIM.

KEYWORDS: BIM, human-centred, technology-centred, implementation, development

INTRODUCTION

Building Information Modelling (BIM) has become a significant topic for the UK construction industry due to the UK government's decree (UK Cabinet Office 2012), promotion of its potential benefits (e.g. Azhar 2011) and expectations of consequent business improvement (e.g. Gu et al. 2008). However, despite these push factors, it has been argued internationally, that the BIM adoption rate is slower than anticipated (Azhar 2011; Gu et al. 2008; Gu & London 2010) and its full potential has not been realized where it is implemented (Brewer & Gajendran 2012).

It is stated that in addition to technology implementation, BIM implementation should include process and organizational changes in order to realize its potential benefits and these changes should consider people issues (Gu & London 2010; Arayici et al. 2011; Olatunji 2011). Furthermore, it has been argued that the inability to realize the full potential of BIM is connected to people issues (Neff et al. 2010; Brewer & Gajendran 2012). In a similar way, Hartmann et al. (2012) criticize the top-down, technology-push approach that dominates the BIM implementation literature. Here, the top-down, technology-push approach suggests that business processes need to be aligned to a new way of working that BIM requires to realize its benefits. Their argument does not mean that the majority of existing work does not pay attention to people issues but rather suggests that their starting position for problem statement and problem resolution is more technology-centred.

This paper picks up this last point and uses it to consider the different views of BIM between objectivist/technology-centred perspectives and constructivist/human-centred perspectives. The paper adopts a human-centred perspective to counter the dominance of the technology-centred view (Hartmann et al. 2012) and argues for a more balanced view of BIM for positive change. Literature is presented which demonstrates extremes of views to clearly show their fundamental differences. It is argued that the polarization is set by the problem formulator's view of the connections between technology, organizations and people. According to the view they adopt, authors can see technological issues from human-centred perspective, or people issues with a technology-centred perspective. Thus, it is the way that each addresses the other that is problematic. Empirical evidence from interviews in a multi-disciplinary engineering practice shows that individuals are confused by their use of BIM because of the dominant technology-centred perspective overlooks some important issues that can be addressed with a human-centred perspective. It is argued that this makes collaboration difficult and successful development of BIM impossible. It is concluded that recognising these differences in perspective is essential so that a better understanding of the management issues can be achieved which would lead to effective solutions for the advancement of BIM.

The paper takes a critical realist position (Ackroyd & Fleetwood 2000; Mingers 2008) as being the most suitable for the practical task of researching how to use BIM better. This sees the physical world and technology as factually real but accepts that human views and actions of this are socially constructed. Key to a robust enquiry is to adopt a wide critical perspective on both ideas and practice.

LITERATURE

Information Technology (IT) perspectives

By its nature, the IT world is dominated by a technology view of problems. UK Government's BIM Industry Working Group (2011) also uses this view to identify "exploitable information" as the key driver to produce improvement. Objectification of the word 'information' assumes that the same information has the same meaning for different actors using it (BSI 2007; Mutis & Issa 2012). This view of information directly affects how problems in the world are viewed by reducing them to structured and objective information problems (Gleick 2011). Although definitions of information have been well discussed; the way these definitions are used depends on the view adopted for its conceptualization. Thus, the engineering system centred view sees technology as the driver of change and that people are subsumed into the technology.

The shortcoming was realized in 1980s and continues to be discussed (e.g. Wilson 2000; Theng & Sin 2012). Dervin and Nilan (1986) called for a paradigm shift in information needs and uses area away from a system centred view (that they call traditional view) to a user centred view (that they call alternative view). According to Dervin and Nilan (1986), the traditional view sees information as objective and as something to be transmitted in quantified packages from the system to users, where users are seen as input-output processors of information. This perspective focuses on externally observable dimensions of behaviour and events to search for propositions that are valid for different situations so emphasising the 'what' of systems.

In contrast, Dervin and Nilan's (1986) alternative view, posits information as something constructed by its users, human beings. Human beings are constantly freely constructing information (within system constraints) in relation to the system and the situational context; and therefore search for universal dimensions of sense-making thus emphasising the 'how' of systems.

Organizational perspectives

In a similar way to information, organizations can be viewed as machines or as social enterprises. BIM related studies (e.g. Gu & London 2010; Arayici et al. 2011) tend to see organizations as process systems which respond to the changing external environment (Lindsay et al. 2003). These systems can be seen as technology or human driven and this determines the approach to how business processes are modelled.

The technology-centred perspective of business process modelling adopts a simplistic view consisting of general input-process-output streams with clear start and end points. It has been argued that this approach is most suitable for production-line like, standardizable and automatable business processes (Lindsay et al. 2003). Many authors emphasize the difference of nature between production processes and goal-oriented processes in terms of process modelling (e.g. Lindsay et al. 2003; Kueng 2005). They claim that the analysis of activities which is done to model production processes is not appropriate to model office workflow, coordination processes and decision-making processes or, in other words, goal-oriented processes. Thus, the deterministic view is criticised for overlooking many hard-to-model important aspects of real life business practices (Melao & Pidd 2000; Lindsay et al. 2003). The human-centred perspective of process modelling some of which are listed in Table 1 accommodates these aspects.

Table 1: Different Techniques of Human-Centred Process Modelling

Author (Year)	Brief Explanation
Yu (1995)	i star Framework: A process modelling framework considering strategic dependencies of agents and issues and the concerns that agents have about existing processes and proposed alternatives.
Van Der Aalst (2012)	Process Mining: Analysis of collected event logs of activities in the processes for process discovery, monitoring and improvement. This technique has also been used for organizational perspectives and decision points analyses.
Dustdar et al. (2005)	Ad-hoc Process Mining: In this study authors aimed to explore ad-hoc processes which are described as “completely unstructured processes” using process mining.
Xia & Wei (2008)	A context driven business process adaptation approach in which business process context can be gathered and reasoned to modify business process structure.
Stoitsev et al.	A conceptual framework for unobtrusive support of unstructured,

(2007)	knowledge-intensive business processes.
Koschmider et al. (2010)	Social Software for Process Modelling: Use of social networks to help users to behave as modellers. Users are guided within the context of an existing Recommendation-Based BPM Support System to which social features are added.
Chan & Choi (1997)	Soft systems Methodology (SSM) is applied in Business Process Reengineering.

Melao and Pidd (2000) overview process modelling and relate different approaches to the philosophical stand points shown in Figure 1; for example, most of the techniques listed in Table 1 fall to the right half. The human-centred process modelling shows that deterministic modelling limits business practices and fails to assist innovation and creative improvisation (Brown & Duguid 2000). Lee (2005) argues for achieving a balance between business process optimization through modelling and the use of human-centred and human-driven business practices.

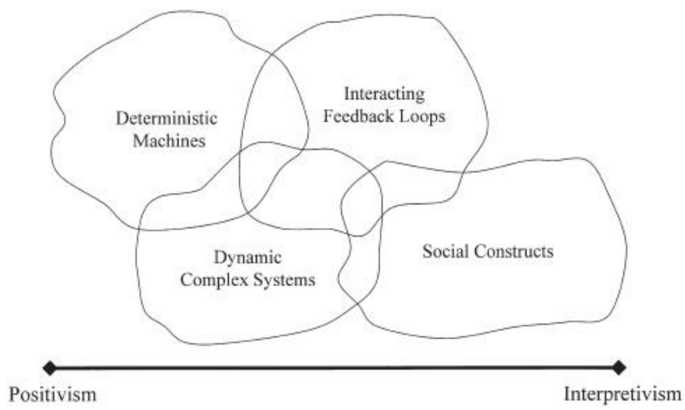

Figure 1: Business Process Views against Paradigms (Melao & Pidd 2000)

People perspectives

Although people perspectives tend to adopt a human-centred view, many authors writing about IT see people as machines (Brown & Duguid 2000, Brewer & Gajendran 2012). People live and work within organizational social settings and this leads to an explanation of behaviour set by organizational cultures. This is a disputed concept (Wright 1994) but can be taken as an explanation of how people within organizations create, shape and are affected by shared cognitive, affective and behavioural patterns. The centrality of organizational culture to organizational life is emphasised by several authors (e.g. Smircich 1983; Alvesson 2002).

Smircich's (1983) work focuses on two extreme views of organizational culture: functional and non-functional, which provides the argument for the differences adopted in this paper. The functional view emphasises prediction, generalizability, causality and control. This view sees culture as a variable among many others and as something an organization "has". Such a view considers that culture can be consciously managed to improve organizational performance due to its causal nature. Consequently, the functional view reduces culture to limited aspects that are perceived from an organizational performance point of view (Smircich 1983; Gajendran et al. 2012).

In contrast, a non-functional view explains culture as part of observable human behaviour, thus, is seen as something an organization "is". Informal aspects of organizations are seen as important and need to be explored to develop organizations (Smircich 1983; Gajendran et al. 2012).

BIM IN PRACTICE

Semi-structured interviews were conducted with professionals from the Birmingham, UK office of a multidisciplinary engineering company which has been established for forty years in the UK and now operates in twenty locations around the world with over four hundred staff. The interviews were conducted with an associate partner, two mechanical engineers, two energy modelling engineers, one structural engineer and one acoustic engineer. The interviews aimed to gain insight into the changes that occurred with the implementation of BIM and about their perceptions of BIM.

Although these people were engineers and so inclined to have a technological perspective and be supportive of technology such as BIM, this did not dominate their practice. For example, the acoustic and energy modelling engineers did not interact with any collaborative BIM software. Both disciplines believed that the inputs and outputs of their discipline are different in nature than other disciplines and that there is no need to be integrated in a merged building model. However, energy modelling engineers stated that if there was a plug-in which ensures the seamless interoperability between the model and their proprietary software they would use it. Nevertheless, they added that even in this situation they would doubt the accuracy of data entered by other parties and probably be cautious about using it.

Although the majority of interviewees were aware of the capabilities of BIM as a total project delivery approach, all the interviewees saw and used BIM merely as a design coordination platform. This means that i) even the disciplines interacting with BIM software (i.e. mechanical and structural engineers) create their design solutions the way they used to do in 2D form and then transfer it to BIM platform for clash detection and drawing generation; ii) BIM software capabilities are not being fully exploited and no object information other than geometrical information is entered in 3D models (i.e. schedules and specifications are created as separate text documents to be printed out and not linked to models). While the software that the structural engineer uses for structural analysis has an export feature to the collaborative BIM tool, this is not the case for mechanical engineers because they create their preliminary solutions through sketches and 2D drawings.

- The reasons identified by the interviewees to explain their approach to BIM merely as a design coordination platform are listed below:
- The only perceived advantages of 3D modelling are early clash detection and better design coordination.
- The amount of the detail required in 3D modelling is non-supportive for the preliminary design phase of mechanical engineering discipline.
- Drafting work cannot be delegated to CAD technicians anymore because 3D modelling requires decision making during modelling, thus, increasing the workload

of mechanical engineers. The time needed to embed all design information (visual and non-visual) into the model is not perceived as adding enough value in return.

- Structural and mechanical engineers considered the necessity to fully detail 3D models which then generated 2D drawings as a negative effect.
- The amount and type of information that contractors use has not changed. They don't use 3D models and ask for 2D drawings.
- There is a belief that the control and tracing of the non-visual design information (e.g. specifications) is more difficult in the model than when it is in spread sheet tables and/or text documents.
- Senior engineers sign off design documents but do not have BIM knowledge.
- Software interoperability problems are not currently resolved.

On the other hand all the interviewees agreed that implementation of BIM improved coordination within the team and between the teams of different companies. They stated that the nature of 3D modelling which is transparent and which requires design decisions to be made earlier increased communication. Increased communication, clash detection meetings and better visualization made people to better understand others' work. However it was also stated by the interviewees that unlike communication, the collaboration between the parties hasn't improved. All the interviewees see BIM as an important part of the future of the construction industry but it needs to be supported by training and go through significant rationalization.

DISCUSSION

The interviews were analyzed to understand BIM practices in: i) adopting BIM tools ii) shaping business processes, and iii) addressing collaboration which revealed the significance of the added complexity introduced by BIM.

Making sense of use of IT in BIM

The interviews revealed that the only pure technological problem for the use of BIM merely as a design coordination platform is interoperability. All other reasons show the importance of making sense of the use of IT for people to make them use a particular IT, just like human-centred perspective of IT would suggest. A technology-centred perspective would assume that the functionalities embedded in IT would be used by its users. However, despite better visualisation and more sophisticated tools provided by BIM software, all the disciplines interviewed have created their design solutions as they used to do in the 2D tradition. The major reason for this is that all the interviewed disciplines believe that the creative design processes they used previously are good enough and they do not need to be changed. For example, mechanical engineers keep using sketches and 2D drawings for their preliminary design and they find this method to be faster and more efficient. They claim that 3D modelling requires too much detail to be entered into the model from the beginning and that this much detail is unnecessary when multiple design solutions are being evaluated to choose the best one. Furthermore, pen and paper are not just old fashioned tools that they use to communicate their design but are part of their creative process.

A similar situation is reported by Harty (2008) for the case he studied where a planned project based shift from pen and paper sketches and 2D CAD drawings to 3D modelling faced strong resistance from the design team. He claimed that people resisted because the implemented vision and artefacts did not account for the other material objects that were an integral part of designing and drafting. Consequently new processes were seen as discontinuous with existing ways of working. Gustavsson et al. (2012) explain that design is a proactive and iterative process where the designer uses a unique combination of practical, theoretical and tacit knowledge which cannot be achieved by any technology. This particular nature of the design process is currently not being supported by IT solutions. Therefore, designers use a combination of different methods (i.e. both manual and technology based) and only use IT when they make sense of its use.

Practice is Business Process (BP)

The company's BIM strategy stated by the associate partner and most of the engineers emphasised BIM as a "selling point" and "catch phrase" for the company. Thus, there was a necessity to use BIM but not a need for extended use. This situation, to some extent, gives more power to people using BIM tools in determining the scope of the BIM related change in BPs. Although BIM tools have capabilities beyond design coordination and interviewees are knowledgeable about them; BIM practices played a critical role in determining the scope of the BP change and led the company to use BIM merely as a design coordination tool.

Automatic clash detection capability and 3D visualization are the obvious, immediate benefits of BIM even in cases where any non-geometric object information is not entered into the model. Therefore, it can be argued that under a vague and non-leading organizational strategy, it is only the immediate benefits that are adopted. In practice then, BIM tools are only used for the tasks where users made sense of the BIM way of working, in this case design coordination. Thus, BPs are not evolved in the direction of BIM's capabilities but had minor changes with implementation of BIM because of the way it is used in practice. In this case, people's use of BIM was the limiting factor however as this didn't disturb current strategy and technological capabilities, a pragmatic congruence is achieved. Moreover, the positive current and future perceptions of the interviewees about BIM, despite their limited use of BIM technology, can also be related to this congruence. This example demonstrates the power of practice in shaping BPs in organizations.

This is in line with Linderoth and Pellegrino (2005) as they showed the way IT is used in practice is an important factor in determining the scope of realized change in IT implementation projects. They identified that strategy, the perceived nature of technology and the use of technology are inter-related and inter-dependent with varying emphasis on the different relations between these three elements according to the stage of implementation and use. In accordance with our findings, they claim that congruence should be established between the strategy, the nature of technology and the use of technology for the change to occur.

BIM Tools, Interoperability and Collaborative Culture

All interviewees agreed that implementation of BIM improved coordination within and between the project teams. Engineers interacting with BIM software stated that 3D modelling made the design more transparent and this pushed team members to think more about their solutions and its consequences earlier. In the 2D tradition, different service headings could work separately and meet less frequently for coordination. However, in 3D environment there is a need for people to contact each other more to understand others' solutions before proceeding with theirs. Interestingly, when the definition of collaboration was made explicit to the interviewees as "creation of collaborative and innovative solutions with shared goals", they stated that the level of collaboration hasn't changed. Furthermore, one of the mechanical engineers stated that "sharing (of the model) doesn't make a better team". Interviewees stated that design meetings focus on problem identification and discussion rather than the creation of collaborative and innovative solutions. Interviewees saw the 3D model as a facilitator in design meetings with the common, understandable and visual information it provides. However, they also stated that this enhanced understanding of other parties' work doesn't necessarily encourage them to collaborate.

Similar findings were presented by Neff et al. (2010) who argued that while there are instances where BIM tools may improve collaboration and communication within the teams, it is not due to its ability to close the informational gaps between disciplines. Furthermore, they argue that the lack of flexibility of the information created and stored with BIM tools hinders inter-organizational collaboration and group working. They argue that BIM tools reflect and amplify the disciplinary representations instead of supporting collaboration. Moreover, Homayouni et al.'s (2010) findings suggest that the theoretical categories of successful collaboration are the same for BIM enabled projects as projects without BIM. Similarly, Dossick and Neff (2011) present transparent and reliable technology and communication as the key factors for effective inter-organizational team work with a strong emphasis on the importance of informal, active and flexible visual communication. Therefore, it can be argued that the belief that improved information sharing capabilities (i.e. better interoperability) leads to improved collaboration is not correct. Thus there is not a direct causal relationship between the technological tools alone and change in collaboration culture.

Over Simplification of a Complex Realm?

Construction projects are characterised by their technical and organizational complexity (Dubois & Gadde 2002). Therefore, the construction industry should be ready to face the added complexity when implementing BIM. However, complex systems require the whole to work beyond the capacity of the details (Bertelsen 2004). The adoption of technology-centred perspective of BIM leads to an abstraction of real life practices inducing a limited understanding of their effects, thus severely curtailing sense-making. Koskela and Vrijhoef (2001) make a similar argument stating that one of the main deficiencies of the current construction theory, in terms of innovation activity, is its abstraction of uncertainty and interdependence. Consequently, business improvement attempts made from such an abstract perspective would have limited effects.

Managers and problem solvers should acknowledge the added complexity in the adoption of BIM and avoid having too many expectations from technology-centred approaches (Brown & Duguid 2000). It is argued that a balanced view of BIM should be adopted to understand the challenges of BIM and to create solutions. Moreover, the complex nature of this area should be embraced as an important input for problem statement, problem resolution and management (Brown & Duguid 2000; Bertelsen 2004; Gajendran et al. 2012).

CONCLUSIONS

This paper has demonstrated how the currently dominant technology-centred perspective of BIM requires a human-centred perspective to enhance our understanding about BIM developments. The extremes of views in terms of IT, organizational and people issues were presented from the literature which provided an understanding of the differences between the perspectives and a robust enquiry frame for researchers and practitioners. It was argued that due to the complex nature of construction projects, a delicate balance between the technology-centred perspective (i.e. which is characterized as simplistic, structured, deterministic, mechanistic and causal) and human-centred perspective (i.e. which shows a world of practice characterized as complex, unstructured, unpredictable, dynamic, and non-generalizable) is required to better understand the problems of BIM and thus to create positive change.

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PAPER 2

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BIM AND CONCEPTUAL DESIGN SUSTAINABILITY ANALYSIS: AN INFORMATION CATEGORIZATION FRAMEWORK

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ABSTRACT

Sustainability in construction has attracted considerable attention from scholars as well as from regulatory bodies. However, early design stage sustainability analysis remains problematic because of the conflicting factors affecting sustainability, the limited and fragmented project data in hand and deficiencies of existing sustainability analysis software for quick evaluation of conceptual design alternatives. Building Information Modelling's (BIM) information management and integration capabilities present opportunities to support early design sustainability analysis. In this paper, early findings of an on-going BIM based early design sustainability analysis application development project are presented. Through literature review and in-depth interviews with a sustainability professional, an information categorization framework for quick evaluation of different conceptual design alternatives from a sustainability point of view is developed. The framework guides further stages of the application development project and also supports BIM Execution Planning for projects where holistic early design sustainability analysis is intended.

KEYWORDS: BIM, Design, Information management, Information technology, Sustainability.

INTRODUCTION

A widely accepted definition of sustainability is given by the Brundtland Commission as "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p.37). The energy consumption of buildings contributes significantly to global warming which threatens the future of our planet. This fact makes the energy performance of buildings an important issue for their sustainability (Park et al., 2012). However, El-Alfy (2010) states that economical, functionality, durability, aesthetics, ecology, health and sociocultural aspects of a building design are together the factors affecting a building's sustainability. A building's sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different stakeholders of a construction project which can be in conflict (Anastas & Zimmermann, 2003). The inter-relations and inter-dependencies that should be considered for a meaningful sustainability analysis require the collective evaluation of the design information created by different stakeholders of the project design team. Therefore, a collaborative and robust building information management system is desirable to support such analysis (Lam et al., 2004).

Building Information Modelling (BIM) can be defined as the process of development and use of a digital model of the facility intended to be built. The resulting product of BIM, the Building Information Model, has the ambition to be the central hub for all information about the facility from its inception onward (BIM Industry Working Group, 2011). The conceptualization and use of the Building Information Model as the central hub for all information requires all stakeholders of the project to contribute to and exploit this building information in an inter-disciplinary collaborative effort during its whole life cycle. Therefore, BIM is increasingly considered as an Information Technology (IT)-enabled approach that allows better management and representation of building information (Fischer, 2004). Consequently, it is argued that information management capabilities of BIM offer new opportunities for sustainability evaluation and decision-making in building design (Bank et al., 2010; Nguyen et al., 2010).

In this paper we present the early findings of a BIM application development project which aims to provide sustainability professionals (SPs) with a BIM based sustainability analysis tool for the quick evaluation of different conceptual design options. This work follows the design science research paradigm under which "knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artifact" (Hevner et al., 2004, p.75). Considering the audience that this paper addresses (i.e. built environment professionals), emphasis is on "the importance of the problem and the novelty and effectiveness of the solution approach realized in the artifact" (Hevner et al., 2004, p.90). The research methodology involved a literature review and in-depth interviews with a sustainable design professional which is justified as the starting point for practical artifact generation. The research was undertaken by the first author as part of a secondment to a company funded by the European Union Climate - Knowledge and Innovation Community (Climate-KIC). The work reported here is three-fold: first it explores challenges for quick evaluation of different conceptual design alternatives from sustainability perspective; second it shifts its focus to BIM environment and discusses the implications of these challenges on the development of a BIM based early design sustainability analysis tool; and finally it proposes a framework which categorizes the information needed by SPs for quick evaluation of conceptual design alternatives in a BIM based application. It is argued that categorization of the information following the proposed framework would appropriately define and organize the early design project information from sustainability point of view, thus underpin quick evaluation of conceptual design alternatives in a BIM based application.

CHALLENGES OF BIM BASED SUSTAINABILITY ANALYSIS AT CONCEPTUAL DESIGN STAGE

A building's sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different stakeholders in a construction project (Anastas & Zimmermann, 2003). In the traditional, non-BIM design workflow, performance assessments of the design are generally undertaken after the completion of architectural design when the design is almost completed (Soebarto & Williamson, 2001; Schlueter & Thessling, 2009). Such performance assessments consists of several independent (Bank et al., 2010) detailed analyses made by expert software using the detailed design information. Crucially, this detailed information is not available at the early design stages and also involves considerable interpretation by experts (Schlueter & Thessling, 2009). These independent analyses hinder having a holistic understanding of sustainability issues and presenting a holistic sustainable design solution (Bank et al., 2010).

The performance assessments made at late stages of the design may lead to design of buildings that have only limited sustainability e.g. in terms of services but not in architectural aspects (Schlueter & Thessling, 2009). The performance assessments that are undertaken at late stages of design also lead to adoption of bolt-on solutions rather than holistic solutions to fix the unsatisfied target sustainability criteria. This is due to the impossibility of making big design changes at late stages of design development because of the concerns about cost and time. Sustainability and environmental impact issues of a building require to be considered before the conceptual design stage and these considerations should be reflected in the conceptual design alternatives to achieve the sustainability targets (Ding, 2008). It is widely acknowledged that most of the key design decisions affecting the building's sustainability are made during early design stage and these decisions that are made at early design stage have the greatest impacts on the cost as well (Bank et al., 2010). Therefore, one of the challenges is to find a design evaluation method suitable for early design stage that provides enough understanding of the design for decision making (Brahme et al., 2001). At conceptual design stage, sustainability analysis method and criteria should not rely on detailed design information which will be generated later by the designers (Ding, 2008).

Sustainable building design is a matter of optimization of several different aspects of a building because of the conflicting nature of some of the factors affecting sustainability (Anastas & Zimmermann, 2003). For example, the most environment friendly functional systems configuration for a building, may not always be the most aesthetic and/or cost efficient solution. Optimization requires overall consideration of information provided by different disciplines with different foci against target sustainability criteria. This creates several challenges for early design sustainability analysis. First of all, a sustainability professional (SP) with an overarching focus is required for the translation of client needs and project specific constraints to determine the target sustainability performance criteria.

Second, relevant design information from different disciplines need to be integrated, reachable and exploitable in order to conduct an inclusive sustainability analysis (Nguyen et al., 2010; Wong & Fan, 2013). However exploitability is a relative quality which depends on the intended use of information. Mutis and Issa (2012) stated that users from different backgrounds of an integrated and shared building model may have problems making sense of the information embedded into the model due to semantic gaps between the ways this information is presented to them and the way they need to use it to perform their tasks. This means that, in order to enable SPs to benefit from the information embedded into the model for analysis and interpretation; design information should be presented in a way that can be made sense of it. Once this condition is satisfied, SPs (who are knowledgeable about different aspects of sustainability at systems-level) can interpret results to support decision making.

Finally, although building assessment schemes such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) were not designed to be used as design guidelines, they are increasingly being used as such (Cole, 1999). This is also an important deficiency in sustainability analysis. The credit-weighting approach which compound to the final score of the building being assessed is the heart of building assessment schemes and there is no consensus for the weightings used (Cole, 1998; Lee et al., 2002). Ding (2008, p.457) criticizes that "the overall performance score is obtained by a simple aggregation of all the points awarded to each criterion. All criteria are assumed to be of equal importance and there is no order of importance for criteria". Mainly due to conflicting nature of some of the factors affecting sustainability, Ding (2008) adds that the criteria should be developed according to each project's aims and conditions. It can also be argued that, pre-defined criteria (i.e. criteria which are not project specific) of building assessment schemes may hinder some sustainable design avenues, making designers focus on high and relatively easily gained credits provided under some pre-defined headings of the scheme while disfavoring some others.

BIM INFORMATION NEEDS FOR SUSTAINABILITY IN CONCEPTUAL DESIGN

Two approaches are identified in the literature for BIM based sustainability analysis applications. Some research concentrates on integration of existing and widely accepted sustainability performance analysis tools (e.g. IES - Integrated Environmental Solutions-Virtual Environment) with other widely accepted collaborative BIM tools (e.g. Stumpf et al., 2009; Azhar et al., 2011) whereas some other research aims to develop new analysis tools that are able to communicate with widely accepted collaborative BIM tools (e.g. Schlueter & Thesseling, 2009; Nguyen et al., 2010). Park et al. (2012) make the point that high development costs, usability and interoperability issues of adapting existing energy analysis software need to be considered when deciding which approach to use. These considerations together with the challenges identified in the previous section led the application development team to create a new early design sustainability analysis application for quick evaluation of different conceptual design options.

Although there is on-going research and development that aims to provide seamless interoperability between collaborative BIM tools (e.g. Autodesk NavisWorks) and widely used sustainability analysis software (e.g. IES), there are still interoperability problems. Transfer of the building model from collaborative BIM tools to proprietary sustainability analysis tools causes loss of information in many instances. Therefore, development of a new application using the Application Programming Interfaces (APIs) to communicate with dominant collaborative BIM tools in the market was preferred.

There are also some other important issues regarding the usability (i.e. exploitability of the information) of existing applications. Firstly, it is revealed from the interviews that a level of understanding of a wide range of technical domains (i.e. building materials, mechanical engineering etc.) is required to benefit from the outputs of the analyses conducted by existing, widely used sustainability analysis tools. This is seen as a deficiency considering the fact that at conceptual design stage the effects of different building sub-system configurations (e.g. type of external fabric, heat generation and distribution systems) and their advantages and disadvantages need to be shared with the client and other stakeholders in a way they can make sense of it. Thus, it is believed by the project team that development of a new early design stage sustainability analysis tool would allow them to present the outputs of analyses in a more meaningful way for client and other design team members and even for other stakeholders of the project.

Tailored outputs that highlight needs and demands of different stakeholders at early design stage would encourage and facilitate discussion around different aspects of sustainable design in construction. This point is even more important when the soft issues (e.g. sociocultural aspects) or qualitative data (e.g. environmental sustainability criteria which are not quantitatively defined yet at early design stage) are to be considered during early design stage sustainability analysis. Although the application development project reported in this paper doesn't aim to integrate the qualitative information and soft aspects of sustainable design into the BIM based application to be developed, it is argued that thoughtfully tailored outputs can be created to support and facilitate the discussion around these qualitative information and soft aspects of sustainable design at early design stage.

Furthermore, it is also revealed from the interviews that the existing sustainability analysis tools don't provide enough flexibility to easily change the building systems' configurations (e.g. type of external fabric, glazing percentage, energy generation and distribution systems) at level required (i.e. systems level) for conceptual design evaluation. Many objects of the model in the sustainability analysis tool need to be selected individually and dropdown menus need to reconfigure the model to evaluate the effects of systems configuration alternatives. It is believed by the project team that development of a new early design stage sustainability analysis tool would be more convenient as it would allow the project team to group the information embedded in the collaborative building model according to their needs and therefore provide a more flexible and suitable working environment for evaluation of different building systems configurations. Finally, because of the deficiencies in their credit-weighting approach and their pre-defined criteria that don't reflect project peculiarities; development of a new information framework that suits early design holistic sustainability analysis is preferred rather than following an existing building assessment scheme (e.g. LEED) for information categorization and sustainability evaluation.

CATEGORIZATION OF INFORMATION FOR EARLY DESIGN SUSTAINABILITY ANALYSIS

The application development work is initially concerned with the construction projects in UK. Consequently, in this paper, The RIBA (The Royal Institute of British Architects) Plan of Work 2007 which is the UK model for the organization of building design, construction and operation processes is used to refer to different project stages. The RIBA Plan of Work 2007 consists of eleven key work stages which are: Project Appraisal (Stage A), Design Brief (Stage B), Conceptual Design (Stage C), Design Development (Stage D), Technical Design (Stage E), Production Information (Stage F), Tender Documentation (Stage G), Tender Action (Stage H), Mobilization (Stage I), Construction to Practical Completion (Stage J) and Post Practical Completion (Stage K).

Sustainability issues of a building need to be considered even before the conceptual design stage and these considerations should be reflected in the conceptual design alternatives to effectively achieve the sustainability (Ding, 2008). This view is supported by the interviewed SP who stated that building functionality, site conditions, target building performance criteria, budgetary and time limits should be understood and documented during project appraisal (RIBA Stage A) and design brief (RIBA Stage B) stages to enable an efficient sustainable design starting from conceptual design stage (RIBA Stage C). The in-depth interviews revealed that sustainability professionals divide RIBA Stage C into three consecutive sub-stages. These sub-stages and their aims are presented in Figure 1. The first sub-stage is for selection of the building system. It is stated by the interviewee that spread sheet applications can be used for this sub-stage because at this stage, evaluation of each building system alternative mainly depends on experience as well as insight about the historical data and limited project specific information in hand. Following the building system assessment, a sustainability pre-assessment meeting needs to be organized. This meeting is important to inform design team members about the sustainability criteria established during RIBA Stages A and B and therefore to enable development of comparable and satisfactory conceptual design alternatives.

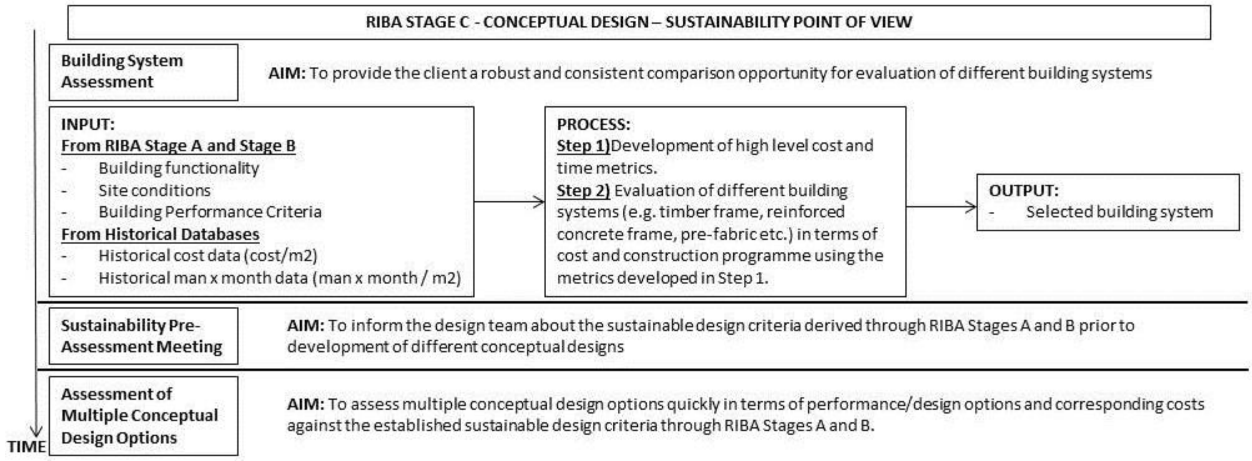

Figure 1: RIBA Stage C (conceptual design stage) from sustainability point of view

The third sub-stage is the evaluation of the conceptual design alternatives. It was decided that this sub-stage can be leveraged by the computer application to be developed. As stated in the previous section, it was decided that the new application would use the information embedded in the building information model created by different contributing parties and merged under a collaborative BIM tool. This means that the model doesn't need to be transferred into the application to conduct sustainability analysis with the application extracting the information needed for sustainability analysis from the collaborative building model. This requires the robust structuring of the information to be entered into the model for later use by SP and other analysis applications to enable quick evaluation of conceptual design alternatives.

Detailed structuring (i.e. identification of parameters and attributes to be assigned to objects and/or systems/sub-systems in the model) of the information is not in the scope of this paper and will be undertaken at later stages of the application development project. Moreover, the detailed structuring of the information to be entered into the model will change according to the collaborative BIM software that the application would be integrated with. However, a general framework which would underpin the detailed structuring of the information has been developed and presented in Figure 2. This framework categorizes the information required for quick evaluation of conceptual design alternatives from sustainability perspective considering and connecting SP's and analysis application's needs.

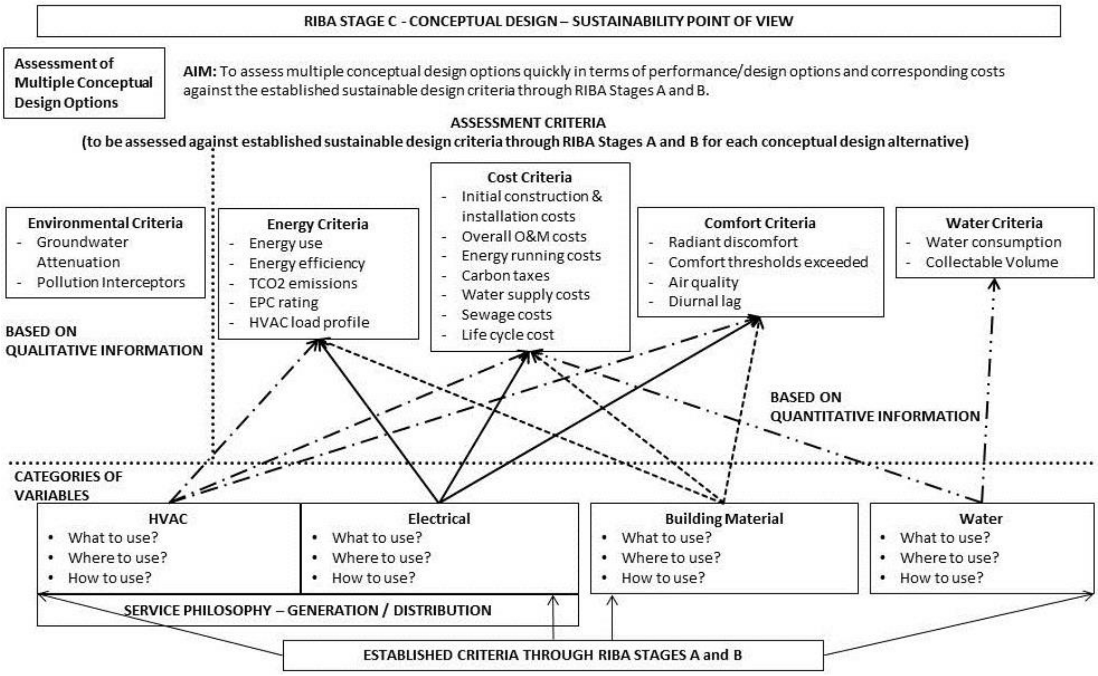

Figure 2: Categorization of the required information for sustainability analysis

The assessment criteria categories identified through the interviews represent the different aspects of sustainable building design which are needed to be evaluated for each conceptual design alternative at RIBA Stage C. Among them, the "Environmental Criteria" category is mainly based on qualitative information at RIBA Stage C; therefore, it was decided that it would be kept out of the analysis application. The arrows drawn between variable categories and assessment criteria categories show the contributions of each variable category to different criteria categories.

The answers to the questions under each variable category determines the required level of detail (i.e. what question) and contextual information (i.e. where and how questions) in order to satisfy application's computational needs and SP's application usability needs. It is argued that a BIM application which allows quick and easy reconfiguration of these variables would allow SPs to quickly and efficiently evaluate different configurations of systems/sub-systems of conceptual designs through meaningful presentation of their implications on sustainability.

The interviews revealed that SP wants to be able to evaluate different systems/sub-systems under four variable categories at conceptual design stage: HVAC, electrical, building material and water fittings. A critical task here is to identify the level of detail and perspective of information that would be addressed asking "what", "where", and "how" questions for each variable category. It is very likely that more than one answer representing a different perspective for each variable under each category would be used for holistic evaluation. For example in the HVAC category, the “what” question should distinguish whether the whole system or distribution and heat generation systems should be addressed (i.e. different level of details)? At the same time, the HVAC system can also be described as an energy conversion system (i.e. representation of a different perspective). The same situation applies to "where" and "how" questions. For example, again for the HVAC category, the answer to “where” question would address both different heating/cooling zones in the building and the positions of the spaces in relation to building orientation. Again for the HVAC category, the “how” question should identify the performance information needed for each element identified under the "what" question. The performance here can be energy performance but it can also be thermal performance. It is argued that, answers to these questions would give a clear understanding of expectations of SPs from the application to be developed.

Due to the different stakeholders’ contribution to a single final product (i.e. a building), organization of the information has always been a concern in contemporary construction industry. This concern is further increased in BIM enabled projects where there is a strong emphasis on information interoperability. Similarly, in order to answer the questions in the framework without causing any confusion between different stakeholders, using a predefined structure for the organization of the information is beneficial. There are several different built environment information classification systems in use around the world (e.g. OmniClass, Uniclass). Among these information classification systems, Uniclass is the UK implementation of the international standard ISO 12006-2 (Building construction - Organization of information about construction works - Part 2: Framework for classification of information).

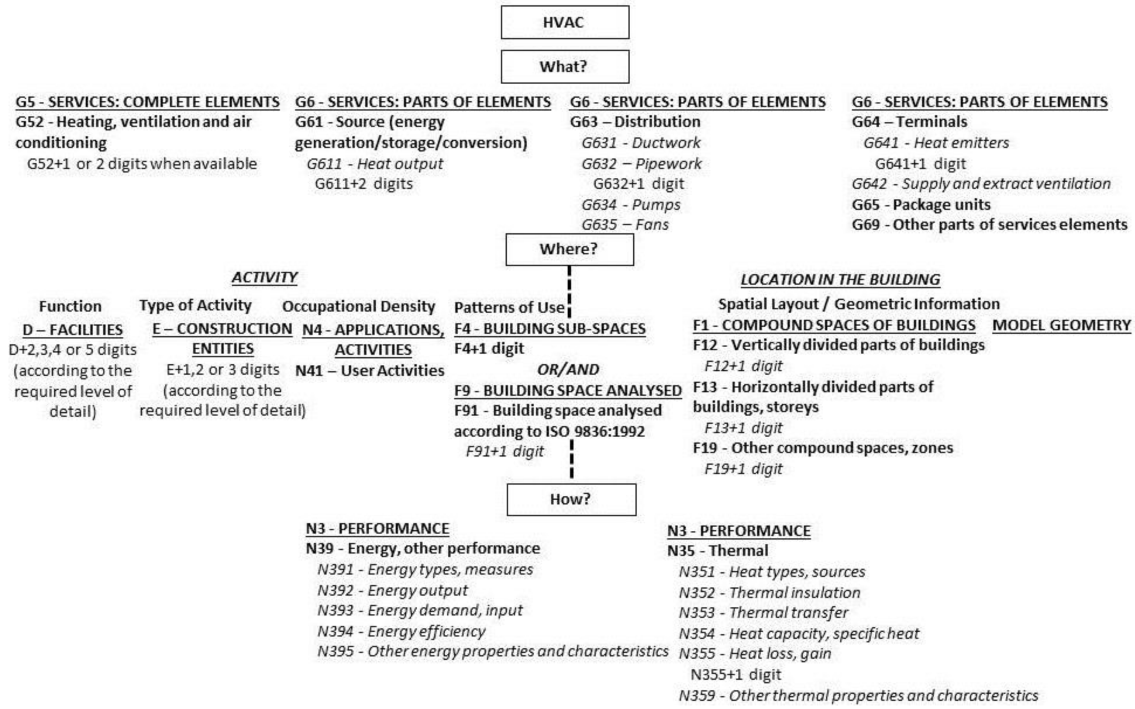

Figure 3: Use of the proposed information categorization framework with Uniclass 1.4.

Uniclass provides a robust information classification structure for the built environment. Furthermore, Uniclass provides the flexibility to identify different levels of detail and perspectives of information necessary for the proposed framework. For example, in Uniclass 1.4, the information about the user activities in a building can be classified under the Table N4 – Applications & Activities - N41 – User Activites (i.e. a particular perspective for answering the “where” question for the HVAC category considering the occupational density). At the same time, the information about building sub-spaces (e.g. working space, activity space etc.) can be classified under the Table F4 – Building Sub-spaces (i.e. another particular perspective for answering again the “where” question for the HVAC category this time considering the patterns of use). Additionally, the breakdown structure of each table in Uniclass allows its users to choose the level of detail they are concerned with. A demonstration of how Uniclass can be used to structure the information acquired answering the questions in the framework are presented in Figure 3 using Uniclass 1.4.

Consequently, it is argued that Uniclass is a beneficial classification system that can be used for the organization of the information addressed by the questions asked in the developed framework. Therefore, using Uniclass, or another information classification system with similar features, would help to avoid information organization problems such as overlap, confusion and misinterpretation in the application of the developed framework (e.g. development of BIM based early design sustainability analysis application; BIM Execution planning for the projects where a holistic early design sustainability analysis is intended).

CONCLUSIONS

Sustainability in construction has attracted considerable attention from scholars as well as from regulatory bodies. However, early design stage sustainability analysis remains problematic because of the conflicting factors affecting sustainability, the limited and fragmented project data in hand at early design stage and deficiencies of existing sustainability analysis software for quick evaluation of conceptual design alternatives from sustainability perspective. BIM's building information management and integration capabilities present opportunities to support early design sustainability analysis. However, in order to benefit from BIM's capabilities, the requirements of early design sustainability analysis need to be well understood.

This paper developed an information categorization framework to enable SPs to quickly evaluate multiple conceptual design alternatives in BIM environment. The framework allows the identification and connection of the building aspects necessary for optimization in the early design. This categorization also guides the future stages of the application development project when the detailed information needs will be refined. Furthermore, this categorization can be used as a support tool for BIM Execution Planning for the projects where a holistic early design sustainability analysis is intended to be conducted. The limited results used in this paper may imply that the conclusions are not generalizable and so will be validated further through more interviews, workshops and software testing. Such future research to validate the categorization presented in this paper will lead to a better understanding of early design sustainability analysis and better applications supporting it.

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LEVERAGING COLLABORATION THROUGH THE USE OF BUILDING INFORMATION MODELS

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ABSTRACT

Building information models are a major new means of design information communication and therefore they are of primary importance for successful design collaboration. However, in addition to communicating the design information, models are used in many different situations for different purposes by different stakeholders at different stages in construction projects. The developing model is a result of the different situations encountered in its production through the interaction of stakeholders. Consequently, it is important to evaluate different uses of models by different stakeholders collectively in order to understand the implications of these differences on models and therefore on design collaboration. The paper investigates this through two educational building projects and establishes the origins of these differences to identify how particular situations affect the developing model. Findings suggest that a successful collective use of models requires structure and planning but these plans need to be adapted to the situations in order to enable collaboration.

KEYWORDS: BIM, collaboration, design management, modelling.

INTRODUCTION

Design in the construction industry requires different players with different backgrounds and foci to work together. Consequently, efficient interdisciplinary design collaboration is regarded as a critical success factor for construction projects (van Leeuwen 2003). In such practice, communication between different players of the developing project becomes critical, as each player needs to integrate their different sets of skills and knowledge (Sebastian 2011). The literature on collaboration in construction industry shows how a delicate balance between technological, organizational and people issues needs to be reached to collaborate successfully (e.g. Shelbourn et al. 2007). The primary condition to achieve successful collaboration is the establishment of the right social and organizational foundation (Homayouni et. al 2010). Technology, whether paper drawings or Building Information Models, needs to support this by facilitating transparent and reliable communications and this is an important determinant for collaboration in construction projects (e.g. Dossick & Neff 2011).

Among the technological solutions proposed to facilitate communication and therefore to support collaboration, Building Information Modelling (BIM) has become a significant topic for the UK construction industry. BIM can be defined as the process of development and use of a digital model of the facility intended to be built. The resulting product of BIM, the Building Information Model (model), has the ambition of being the central hub for all information about the facility from its inception onward. This information needs to take on many forms in its many roles through the life cycle of the facility. The conceptualization and use of the model as the central hub for all information require all stakeholders of the project to add to and use the building information depository through a collaborative effort (BIM Industry Working Group 2011; UK Cabinet Office 2012). Consequently, there is strong emphasis on inter-disciplinary design information sharing and collaboration in BIM related policies (e.g. BIM Industry Working Group 2011, BSI 2013) and in BIM related research (e.g. Arayici et al. 2011; Shafiq et al. 2013). Although it has been argued that the factors influencing successful inter-organizational collaboration and BIM practice are largely the same (Homayouni et al. 2010), how model based communication should operate in practice in order to enable the collaboration needs to be further explored.

In exploring this, the research assumes that the model is a major means of design information communication in BIM enabled projects and aims to establish how the communication of design, through collective use and sharing of models, needs to operate in order to leverage design collaboration. Through observations and interviews in two projects, the research enquires into how different disciplines decide their modelling approach, how they use other disciplines' models for their own purposes and what kind of modelling and other type of arrangements are taking place to maintain satisfactory design communication based on models. From this it establishes how models are not only used for sharing design information and design collaboration but also actively used for other fundamental functions such as information generation, storage, analysis, representation, control etc. during design development. The advantages and disadvantages (i.e. implications) of certain modelling approaches from design communication point of view are determined but more importantly the origins of these modelling approaches are revealed. It is concluded that different situations in which models are used have impacts on the modelling process and therefore on the resulting models and in order to be successful, planning and management are required to address these situations.

METHODOLOGY

This research takes a critical realist position (Ackroyd & Fleetwood 2000; Mingers 2008) as being the most suitable for the practical task of exploring the use of a same artefact (i.e. model) in different situations where different purposes are dominant. Critical realism sees the physical world and technology as real but recognises that human views and actions of those are socially constructed. The selected approach presumes that, ontologically, models exist independently (i.e. independent from its users) and they have the power of affecting the practice (i.e. the situations) in which they take place with their users. At the same time, it allows the research to capture how different uses of the models in different situations are differently constructed by users and in turn caused changes in the reality (i.e. materiality) of the model.

As part of a larger research project, data were collected from two design-build educational building construction projects. The client, the architect and M&E subcontractor were the same for both projects however M&E consultants were different. The enquiry used semi-structured interviews and observations of the projects to provide robust data so that a wide critical analysis of both ideas and practice could be undertaken. The first author regularly attended the design coordination and clash detection meetings of the second project but only audio recordings of clash detection meetings were used for first project. Insight was gained into in-discipline uses of the models through the semi-structured interviews. The observations in the design coordination and clash detection meetings were used to determine how models were used as design checking artefacts and what kind of modelling and other arrangements were required to satisfy the different uses of the model. The themes under which findings are listed emerged from the analysis of the observational data and previous interviews with projects' stakeholders. These themes were validated during the interviews and in cases when a particular reason for a modelling approach did not fit in an existing theme, a new theme was created. Through this the research gained an insight into how models were affected by different situations (i.e. different uses) that they were exposed to, in order to explore the implications of this on design collaboration.

COLLABORATION AND BIM

Collaborative design, in itself, is a disputed concept that is used interchangeably for different scopes of interaction in design process (Kvan 2000). Kvan (2000) citing Mattessich and Monsey (1992) described cooperation, coordination and collaboration as a spectrum where determinant of authority, risks for interacting parties, and sameness of missions differed. He argued that although there is strong emphasis in the literature on collaborative design, most of the times construction teams only cooperate and compromise. He stated that these are exactly what they should do because collaboration is time consuming and requires relation building. Consequently, he suggested loosely coupled information systems rather than closely coupled ones.

The point made by Kvan (2000) regarding the relation between the scope of social interaction and its relation to the type of information technology (i.e loosely coupled vs. closely coupled) is supported in a more recent study. Homayouni et al. (2010) argued that successful inter-organizational collaboration and successful inter-organizational implementation of BIM have shared "theoretical categories". These are listed as: fostering integrated teams; implementing tools and strategies to encourage clear communication across the team; and developing transparent technology use. Importance of people issues in BIM enabled projects are also argued by others (e.g. Arayici et al. 2011; Olatunji 2011) and it has been stated that in inter-organizational settings, technology adoption process requires mutual adjustment to achieve successful inter-organizational collaboration (Taylor 2007). Similarly, BIM related policies also state that the conceptualization and use of the model as the central hub for all information require all stakeholders of the project to add to and use the model through a collaborative effort (e.g. BIM Industry Working Group 2011) and suggest closely coupled systems such as Common Data Environment (BSI 2013) for technically enabling this. Consequently, the BIM discourse often includes arguments for interdisciplinary communication and collaboration (Homayouni et al. 2010).

However, it has been reported that the level of collaboration in BIM enabled projects are lower than expected and/or not in line with the opportunities provided by current BIM software (e.g. Shafiq et al. 2013). Problems and concerns regarding collaboration in BIM practice have been studied both from technology-centred perspective focusing on functional requirements of the technology (e.g. Isikdag & Underwood 2010) and more comprehensive perspectives considering the developing relations between people, technology and processes for collaboration (e.g. Dossick & Neff 2011). The former category of studies focus on system design and aim to identify system requirements to technically enable closely coupled systems. The latter category aims to determine how organizational settings, in which dynamic relations between people and technology emerge, need to be managed to benefit from BIM.

Related to the concepts of loosely and tightly coupled systems are the ideas of Suchman (2007) on plans and situated action. Suchman discuss what makes artefacts “interactive” in order to explain the meaning people attach to computers in practice. Theoretically, this suggests that computers have intent “as demonstrated precisely in this ability to behave in an accountably rational and intelligible way” (Suchman 2007: 43). This intent is embedded in plans (both inscribed in the software and presented in the management of the task) and the actor’s problem is to find a path from an initial state to a desired end state using the plans. In complex dynamic situations involving people the plans are inadequate and adaption is required in practice which becomes the point of situated action. This can cause problems for other members of a team if one member's adaption provides another's dynamic context as it deviates from the plan. The consequence as Gherardi (2012: 14) states is “The concept of performance, in fact, makes it possible to regard work as an activity which follows a script, but whose interpretation is situated. It is an individual and collective activity that may consequently vary according to the participants involved in it, or those who are prepared to be involved”.

MODELLING APPROACHES IN PRACTICE

As well as plans and situations the research analysis used a number of themes which emerged from the data itself. Central to this analysis is the expected (i.e. planned) "BIM way of working" which is structured (i.e. scripted) and technology driven. However, there are inadequacies in this that require "pragmatic adjustments" and the "contractual requirements" influence modelling approaches which respond to the situatedness of the activity. Further, the practicalities of developing a design through collective developing of a model require "different levels of detail" resulting from the collective and dynamic nature of design development. The ability to check design and coordination using clash detection is a significant part of BIM way of working but the practicalities of this need to be considered both technically and as a collaboration tool.

BIM way of working

In both of the projects, the same BIM platform was used by different disciplines which included an online document management tool to store and exchange design documents. The presence of different packages of the same platform allowed software interoperability. However, it was observed that there was a strong commitment to standardization of the way the model was created particularly through using naming conventions, work set contents and agreements on model contents. This allowed different parties to interrogate the model for their own design development purposes and also for managing clashes. These conventions were partly articulated in BIM Execution Plan (e.g. naming conventions). It was acknowledged by all the parties that creating and following a consistent structure for object development was the key to benefiting from the linked models and to produce the healthy development of design in BIM environment. However this alone was not sufficient due to the complexity of both modelling and design development such that regular on-going discussions were needed to keep the model consistent for all the parties.

The design teams stuck to in-built tools provided by the BIM software as much as possible to avoid the potential problems that might occur because of stepping outside the structured BIM way of working. Therefore, generic objects were only created when existing tools were not able to satisfy the design purposes at particular instances. For example, although they created an object family for furniture, the architects chose to model fitted furniture under a generic objects family. The reason for this was that they wanted the fitted furniture (e.g. reception desk) to be always visible even when they turned off the loose furniture. It took considerable discussion in both projects to decide what to include and what not to include under "Generic Objects Family" but a consensus was achieved and fewer conversations were required after this.

The BIM software has an embedded logic and understanding this logic was important in order to document the design correctly. For example, the editor didn't schedule the wall heights and did not show them correctly at some instances. When the wall intersected with a roof or ceiling, the editor automatically cropped it but when the object was considered in the designer view, it still showed the "unconnected height" which was the height before the automatic crop.

The BIM environment allows the creation of extensive connections between objects and the opportunity of assigning many attributes to the objects. However this requires approaching similar objects with consistency and planning in advance in order to know how these attributes would be used. For example, if rooms are defined as spaces, M&E discipline can use the model to conduct ventilation analyses. Similarly most of the objects can be scheduled automatically if defined consistently in the model. However counting on these automated functions brings its own risks because if there is a problem, it becomes really hard to find where it was generated from. Additionally, the designers need to understand the ways that measurements are performed by software to ensure that what was scheduled is actually what was designed. Curtain walls, for instance were problematic in this sense. The in-built curtain wall tool of the software, takes it is as an opening in the wall however curtain walls' fixing elements span beyond the visible opening in the model, thus, causing potential misunderstandings about the size of the curtain wall in schedules.

A useful feature for designers in BIM environment is that objects are created once and then developed over time. This makes it necessary to assign ownership to each object in order to ensure that they are adequately handled during the design development. This ownership of objects requires more coordination as objects are used by other members of the team. Similarly in BIM environments, different members use different views and the disciplines need to decide from which plane they should cut the model to obtain the view they want for it to be useful to them. Although there is the flexibility to create almost any views, the fact is that not everything is detailed in the model means that extra time is required to enrich the views with annotations.

Pragmatic adjustments to BIM way of working

The BIM way of working is determined by the functionalities of the software however the software does not work universally and so practical pragmatic adjustment need to be made. An example of stepping outside of the "BIM way of working" was about the in-built change tracking features of the software. Designers found the in-built change tracking features complicated to use. Therefore, to compensate, they decided to issue a cover letter every time they issued a new model where they detailed which parts of model were developed.

Additionally, the auto-joint feature of the software did not satisfy the architects in some instances. For example in column-curtain wall joints, this feature extended the wall layers onto the column which was not what was wanted. After long discussions, the architects decided to black out these joints to force people on site to refer to 2D drawings where they could correctly document the joint.

In a similar way, the functionalities of the software were used for pragmatic reasons. For example, architects did not want to connect the walls to the slabs because slab objects were owned by structural engineer. They wanted to be able to turn off the structural elements and still have the walls visible. Although they acknowledged that this is against the logic of parametric design based on the fact that they fixed the heights of levels quite early in the design, they did not think the parametric feature was of value against other purposes. Furthermore, they created red 3D marker objects visible in all views to identify important coordination issues. As these markers were objects in the model, they also could schedule them to see all the pending coordination issues. Similarly, they created placeholder objects to specify objects that they don't own but they needed in order to coordinate their own designs. These placeholder objects were simple representation of the real object and were replaced by fully designed ones when the real owner of the object developed the design to the point that this object was needed. For example, radiators are created as placeholders (i.e. as empty boxes) by the architect to coordinate the room layout but later replaced by radiator objects by M&E designer.

Contractual issues

Contracts are important determinants for how the design is documented. The same views and drawings as pre-BIM practice are still created because the contractual documents in the background are based on 2D drawings. Therefore, as stated by all the interviewees "it is still mainly based on 2D drawings but coordinated through 3D". There is a general disclaimer on the model which says that any information that exists in the model but not in 2D drawings should be checked with the owner of the object. As stated by an architect "there are things that just don't work with a BIM way of working". Similarly, it was explained that the model as a design output can cause arguments between designers and clients. Although the scope and content of the model can be specified, it is impossible to specify every single detail about modelling and the client may end up arguing that the model is not developed appropriately. Therefore, 2D drawings were seen as being helpful to ensure that the design does its job properly and satisfies everyone.

Level of development of design and level of detail of the model

In the projects studied, the initial conceptual design used sketching software, and 2D drawings. The BIM model was created at RIBA Stage C. At Stages C and D mainly generic objects were used. At Stages E and F these generic objects are swapped out with custom ones (i.e. with the objects under custom families). This allowed the model to be flexible so that it could be changed quickly during design development. For example at Stage C, the design team only wanted to see that there was a door in a particular place but they were not interested in any particular property of that door apart from its location and approximate size.

Another issue about the level of detail of the model appeared in clash detection exercises. In many instances for the sake of efficient use of time, objects were deliberately left clashed with each other because of the fixed operation of the modelling software. For example the screed was left to clash with structural columns because everyone knew that the screed will only run up to the columns in reality. Another explanation given for this was that these clashes don't appear in most of the views, especially if they were set to medium or coarse level of details. However, although there were deliberate modelling decisions that do not reflect the reality, all the construction details were correctly included in the generated 2D detailed drawings and the annotations added on them.

The level of detail was also important when the coordination views were created. There was an ongoing discussion between the different disciplines sharing models with each other as each wanted to see different aspects and not see others. It was stated by all the interviewees that when a model was received from another discipline, it was very confusing to have it in the level of detail that the sender used. Therefore, agreements on what and how they want to see were made between the parties.

Design workflow

It was observed that the designers needed the design information stored in the models to develop their own design. Therefore the design workflow was connected with the model development. Individual disciplines use other disciplines' models as input to develop their own models and designs. When there was problem with the synchronization of the model development between the parties, 2D CAD drawings of other disciplines were used to coordinate in-discipline design to maintain the design development.

It was observed that it was impossible for individuals to make decisions only looking at the model because of the iterative and ever developing nature of the design. Therefore conversations were vital no matter how good the models were. These conversations were combined with 2D drawings which were complementary to the model. 2D drawings with their annotations and revision numbers told a necessary story and retained the message about the design intent. Similarly, because of the ever developing nature of design, the model was always incomplete in different ways for different disciplines. At any point in time, the model was only a snapshot of work in progress and designers didn't know what the final design would be. The iterative nature of design required jumping back and forward through different iterations. This caused problems in model based design communication. In one of the projects for example, an electric switch owned by M&E discipline was orphaned when architect deleted a wall which required communication outside of model environment.

Clash detection

In the clash detection exercises, only clashes between highest level object families were checked instead of setting more detailed rules. More detailed rules created an exponential increase in the number of clashes which were already felt to be excessive. Here again, the importance of object naming and structuring conventions was observed. These conventions allowed the designers to manually filter the clashes and to differentiate clashes created due to modelling issues rather than more important design clashes. For example, inset lights clashing with ceilings were never checked because the designers knew that these clashes were due to modelling issues; the lights were not embedded in the ceilings in the model because it was time consuming and such connections slowed down the model. Finally, clash detection exercises and any other model checks were always accompanied by a walk through the model. In many instances, designers detected design or modelling problems during these visual inspections rather than through clash detection exercises.

DISCUSSION

Use of the model as the central hub for all information requires all stakeholders of the project to add to and use the building information depository through a collaborative effort to ensure data integrity (BIM Industry Working Group 2011; UK Cabinet Office 2012). Consequently, there is need for an additional dimension of collaboration (i.e. in addition to design collaboration) in BIM enabled projects which arise from the collective use of the model. Although there is no explicit differentiation in literature between these two dimensions of collaboration (design collaboration and data collaboration), these are implied in BIM related policies (e.g. BIM Industry Working Group 2011; BSI 2013) and in BIM related research (e.g. Shafiq et al. 2013). In order to understand better how design collaboration and data collaboration need to operate, the findings were analysed against the concepts of plans and situated actions. This will also be related to the establishment of closely or loose coupled systems. Clearly a work world dominated by plans is closely coupled and so experiences problems when its context changes such as in design development. It is generally promoted that the structured and accurate nature of the BIM model allows everything to be established through plans. This is challenged below.

What is described as "BIM way of working" in the previous section and the accompanying documents such as BIM Execution Plan and the agreements materialized in them (e.g. naming conventions) can be seen as plans. Collective development and use of models and their storage in a shared platform requires consistency. Project level BIM planning and structure informed by the plans inscribed in the technology by developers are required to establish this consistency. As a result, two types of plans can be articulated in BIM practice. First the plans inscribed in technology by developers and second the plans developed by the construction project team for consistency in order to enable collective development and use of models. The first type of plans allows technology to function properly. This can adapt to different construction projects only to the extent that the software offers a level of adaptation capability through the use of the embedded tools and functions. The second type of plans is created by the construction project team and gives legitimacy and accountability to model as a communicator of design information.

There are problems arising even with the first type of plan involving the data collaboration itself. Object-oriented design software (i.e. BIM software) and its associated rules and procedures have an embedded structure and scripts such as in-built tools, families, functions and data structure which fix and constrain the possibilities of design. However, the purpose of the software is to enable the development of a unique design artefact represented in the model, therefore, its users require the freedom to use different combinations of software features to accomplish the design. The modelling approaches in the case studies showed how the pre-developed rules and plans for the design and the model needed to be adapted to the different situations they encountered in order to accommodate the uncontrollable and unpredictable contingencies arising from these situations.

This adaptation takes place in and through the situated action. In any particular situations involving construction project design, it is argued that models are only a part of the purposeful situated actions. The models themselves are part of the situated action and so are in flux and influenced by the surrounding social and material elements; in addition they are interpreted in the unfolding situations. Therefore, the models are used and affected in different ways in different situations as was shown in the findings by the pragmatic adjustments to BIM way of working, the effects of contractual issues on modelling, the need for different levels of detail in different situations, the iterative and unfinished nature of ongoing design and the need to employ various inspection methods to detect clashes.

The collaborative construction project design work, itself, is run through social arrangements in which different meanings are attached to design by different designers and are negotiated and reconciled along the design development. Models, as a major means of design information communication, act as legitimate and accountable mediators of this negotiation and reconciliation process using the design information they represent. However, other means of communication such as phone calls, e-mails and meetings are needed between different stakeholders in order to sustain the social arrangements between the stakeholders and to reconfirm the accountability and legitimacy of the model as a trustable design information communicator. If communication through models replaces other means of communication justified by extensive planning, then models risk dictating or locking meanings rather than nesting them for negotiation and reconciliation. Therefore, models and accompanying plans should be positioned in design practice in a way that leaves enough space and facilitates meaning negotiation and reconciliation. This means that the way models are seen and the plans that are created should acknowledge and allow adaptations to different situations for successful collaboration.

Consequently, it can be argued that, on one hand model based inter-disciplinary design work requires close coupling and extensive planning to keep the software working and a consistent shared model for everyone. On the other hand inter-disciplinary design work is an iterative and evolving process that requires loosely coupled situations and flexibility to develop. Design is developed as result of various purposeful situated actions along the process and the design artefacts should afford unfolding and evolving nature of design work (Ewenstein & Whyte 2009). We argue that the tension between these two should be acknowledged and managed. This means that, in BIM enabled projects, management needs to accommodate loosely coupled situations in order to enable successful design collaboration.

CONCLUSION

In BIM enabled projects, the model, as a major mean of communication is an important factor that can improve collaboration. However in practice, modelling software is not ideal and the data is needed in different ways by different disciplines. Therefore, it is vital to achieve a harmony between uses of models as design development artefacts and uses of models as design communication artefacts. We argue that the models can only perform well as design communication tools if they also perform well as design development tools and the models which are successful in design communication are able to leverage collaboration in construction projects.

In this paper, it has been shown that there is a tension between plan driven, closely coupled model based design and the loosely coupled situations where design development is performed. Thus future work in BIM needs to explore how this tension should be managed. Although we observed some instances where users of the model "hacked" the software and improvised their own uses to make the model suit their needs, we argue that there are bigger potential opportunities that can be realized for better collaboration. We argue that once project particularities and requirements for design development and communication are established, BIM needs to be tailored according to the needs and particularities of the project and the software needs to enable this.

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COLLABORATION IN BIM ENABLED DESIGN PROJECTS: EFFECTS OF INTEROPERABLE INFORMATION TECHNOLOGIES

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ABSTRACT

There is a growing awareness that the problematic nature of collaboration in construction design projects is further complicated by the use of interoperable information technologies (IT) in Building Information Modelling (BIM) enabled projects. Consequently, there is a need to better understand the ways interoperable IT get involved in inter-disciplinary relations and affect mutual engagement of different design members. Findings from the study of a BIM enabled design project are analysed using the concept of interdependencies in the interactions between practitioners and their organisations. The paper draws a distinction between "model interdependencies" and "design interdependencies" concerned with the IT and the design task respectively. This distinction helps to deal with the complex nature of practice by expressing the different needs people have in their task interactions using technology in organisations. It is concluded that the conflicts between model and design interdependencies cause segregation into separate model development and design development at the organisational level. Project organisations should be aware of this and take necessary social and technological precautions to achieve better design collaboration.

KEYWORDS: BIM, collaboration, design, interdependencies, interoperability

INTRODUCTION

Interoperability of information technologies (IT) refers to the ability to exchange information between different software packages (Ide & Pustejovsky 2010). In Building Information Modelling (BIM) enabled design projects, IT interoperability allows different design team members to contribute to and use data from a shared data repository (i.e. the information model / model) within which design data are stored in a unified and structured way. This is referred to as "integration", in the sense that design data from different design team members are connected together through pre-defined and / or user defined rules (i.e. parametric) (e.g. Whyte 2011; 2013). Such digital integration of design data has been promoted as an enabler of better design team collaboration in BIM; this includes enhanced (and sometimes automated) information generation, analysis, presentation and sharing capabilities (e.g. UK BIM Industry Working Group 2011).

IT interoperability requires specified data formats, communication protocols, and other formal structures to enable communication and data exchange between different packages (Ide & Pustejovsky 2010). In this new design production situation, collaboration is defined by, or at least framed by, data interchange. However, collaboration as mutual engagement is less clearly addressed by data interchange and the implications of mediating collaboration with IT are lost. Previous empirical research has shown that, in construction design projects, digital integration of design data has significant effects on the way design projects are organised (Whyte & Lobo 2010; Whyte 2011). It has been further shown that these effects can become counterproductive for design team collaboration depending on how interoperable IT are framed and used within the project organisation (Neff et al. 2010; Dossick & Neff 2011). Organisational situations where formal, rule based, linear logic of current interoperable IT operations obtruded upon the inter-disciplinary, iterative, to be physically applied, developing and dynamic character of construction design have been described in BIM enabled design projects (Dossick & Neff 2011; Whyte 2013; Cidik et al. 2014). Studies have shown that, in practice, these situations need to be negotiated to be settled and lead to improvised skilful combination of digital and non-digital practices for collaborative accomplishment of the work (Dossick & Neff 2011; Whyte 2011; Cidik et al. 2014). Consequently, new approaches to research into digitally integrated construction design work were urged for critically questioning the interoperable IT in order to achieve a more practically relevant conceptualisation of technology and interoperable IT mediated practices (Whyte 2013).

This paper explores how collaboration is practically accomplished in BIM enabled design projects and critically questions whether the interoperable IT really do support collaboration by facilitating purposeful mutual engagement between the design team members. In particular, it investigates the interdependencies between different members of the design team in the context of a BIM enabled construction design project. Interdependencies within an organisation imply coordination requirements between parties (Thompson 1967; Bailey et al. 2010) and are therefore important to be investigated in the context of collaboration in BIM enabled projects. The paper draws a distinction between "model interdependencies" that refer to the interdependencies imposed by rule based digital integration of design data and "design interdependencies" that refer to other interdependencies that were considered by design team members. Two events that were observed in the collaboration practices of a BIM enabled design project are discussed through the lens of model and design interdependencies.

Adopting a practice-based view of organising (Gherardi 2012), the discussion is further extended to the organisational level through the associations that are made between the findings from practice (i.e. the events) and the organisational routines of the project. Such associations expose connections between features of the interoperable IT and the organisational routines of the project and therefore provide a wide perspective from which the effects of interoperable IT on collaboration can be discussed. This allows a richer discussion of the advantages and capabilities of the technological operations based on the integrated data and corresponding implications on inter-disciplinary collaboration in design.

METHODOLOGY

The problem of investigating collaboration is complex because of the developing and dynamic nature of design work. The relations between the different design stakeholders and the design objects they are using are constantly changing, requiring the organisation to change in order to make collaboration possible. The structured and explicit nature of IT also gives it a false picture of the stability and certainty of the interactions in the project. A practice-based approach (Gherardi 2012) has been adopted in this paper as it allows both exploring the practice level, where sense-making occurs, and making associations between the practice and organisational levels. Moreover, the relational epistemology of a practice-based approach allows an explanation of the complex and evolving web of interactions between people and objects (including those mediated by IT) upon which the design collaboration is based (Gherardi 2012). Furthermore, the relational epistemology of practice-based studies acknowledges that the local (i.e. practices) and global (i.e. organisations) are connected.

The explanatory power of practice-based studies lies in their capability of establishing associations between these levels through zooming-in to the practices and zooming-out to the higher levels such as organisations (Nicolini 2012). The practice-based view presents phenomena that can be observed at higher levels of organisation as the effects of the web of inter-related practices at a lower level. This requires zooming-out, in the sense of observing the dominant discourses, discussions and tendencies within a field (Nicolini 2012). Here, the researcher interprets the collected empirical data through his/her understanding of the wider field. The rigour of such interpretations is ensured through the description of the local-global associations that are in line with empirical findings. In the case of construction design this requires looking at design objects (e.g. drawings) which change their roles in their interactions with people according to the situations they are used in (Ewenstein & Whyte 2009). This produces a definition of design collaboration as a practical accomplishment where people skilfully interact with design objects within a particular situation for development and communication of meanings.

The research uses empirical findings from a BIM enabled new built project in UK. This was an educational building project in its detailed design stage. In addition to the observational data collected from collaborative practices (i.e. design coordination meetings, model coordination and clash detection meetings etc.), open-ended interviews with design project stakeholders were also conducted in order to gain more insight regarding the collected data. The organisations involved did not allow the recording of these meetings but only attendance and interviews. Thus, data was recorded in field notes and the reflections on these were supported by the interviews. The findings will be presented in two sections. First the organisational environment of the project will be described with a particular focus on coordination activities in order to provide a basis for arguing about which activities were significant for the organisation to coordinate and how these were framed. Second, two events from practice will be presented to be interpreted through the lens of model and design interdependencies following Boyd (2013), who argued that studying events are useful for enabling a more holistic study of the adopted practices. Associations will be made between practice and organisational levels through the interpretations based on the insights from BIM and organisational studies literatures. These will allow hypothesising about some of the root causes of the challenges in collaboration in practice that are connected to the structure of interoperable IT and corresponding organisational effects and strategies.

LITERATURE REVIEW

A particular interest in this study is the recent literature on BIM and organising which introduces the problems of design collaboration. This will be followed by presentation of literature on technology, interdependencies and organising to establish a wider theoretical context that is used in the paper.

BIM and Design Collaboration

Empirical research into BIM and inter-disciplinary collaboration has paid particular attention to the organisational effects of interoperable IT for theorising about the effects of BIM on collaboration. Whyte and Lobo (2010) argue that digital integration of design data couples the different members of the design team closer; challenges the conventional boundaries between organisations, disciplines, teams and roles in the design project; and therefore work, involving the integrated data, needs to be highly regulated and formalised in order to be accountable. Nevertheless, they argue that although the interoperable software is set-up to be an integral part of the established formal control structure, control is never total, but rather boundaries, methods, objects and goals are negotiated (Whyte & Lobo 2010). In a similar line of thought, Dossick and Neff (2010) claim that BIM enabled projects with their closer technological coupling do not solve the inherent conflicts between different members of the design team, but make the boundaries more visible and harder to cross (Neff et al. 2010). This requires more leadership to make collaboration possible (Dossick & Neff 2010).

The interoperable IT assume a singular reality and so impose the rules codified in the technologies. Whyte (2013) shows the shortcomings of this for design in construction which has a future physical application. She argues that, in construction, designers cope with the complexities of the physical world through testing their design from multiple perspectives and interoperable IT is limited in these terms (e.g. designers benefited of using physical models in addition to information models) (Whyte 2013). She proposes open information systems for construction design work “in which an evolving and partial digital infrastructure can be used to achieve goals beyond the computer” (Whyte 2013). Neff et al. (2010) and Dossick and Neff (2011) argue that the centralisation and integration of design data produces over-determination and inflexibility in design and makes it harder to work in the inter-disciplinary design settings which require integration of multiple perspectives, knowledges, and standpoints. Dossick and Neff (2011) suggest that interoperable IT should be continuously complemented with informal communication to overcome this shortcoming. In a later article, Dossick and Neff (2014) particularly focus on documentation in BIM enabled design projects and argue that there is a cost attached to documentation in BIM enabled projects due to the fixity that is established by documentation of information in an integrated data repository. They claim that “the price of documentation include[s] an opportunity cost of unimagined solutions as well as the real cost of labour to modify models once developed” (Dossick & Neff 2014). In a similar fashion, Merschbrok and Wahid (2013) study task interdependencies, technological interdependencies and positions of stakeholders in the process chain in construction projects and conclude that in BIM enabled projects, due to the specific ways information is documented and integrated (i.e. forms and formats of information), those who are handed previously documented information are less flexible in their undertakings.

Finally, recent research into BIM and collaboration has also shown that there is a considerable ongoing joint effort of different design team members for the set-up and operation of interoperable IT as anticipated (Whyte 2011; 2013; Jaradat et al. 2013; Cidik et al. 2014). Whyte et al. (2015) argue that the rapid and flexible forms of project organisations, that were unlocked by interoperable IT, have limits in practice because of the lack of trust in the integrity of the information. Cidik et al. (2014) show that the efforts for the set-up and operation of interoperable IT include significant advance planning and documentation followed by ongoing negotiations and re-confirmations regarding the accountability of integrated data as a legitimate source of information. Whyte (2011; 2013) argues that working with interoperable IT requires undertaking processes outside of core design tasks making the success of an integrated technological infrastructure always fragile and only ever partly accomplished (Whyte 2013). Furthermore, Jaradat et al. (2013) claim that the ongoing efforts to keep the digital systems up and running became a central undertaking in the project and this created new roles and forms of accountability which were in conflict with historically established practices.

Technology, Interdependencies and Organising

Woodward (1965) and Perrow (1967) have argued that technologies are determinants of task structures which are essential for the establishment of organisational structures and therefore for communication and control structures. The same argument has been confirmed for IT in more recent studies with emphasis on the significant differences between the ways industrial and information technologies affect the organisational principles (Kallinikos 2006; Suchman 2007). Connected to these arguments, information technologies have been argued to have materiality (Leonardi 2010) due to the particular ways they affect practices as constraining, allowing, encouraging, facilitating, reminding, inviting etc. particular courses of action over the others. However, Suchman (2007) claims that such effects do not necessarily reflect the contingencies that should be addressed in the flow of practices because IT actions are fundamentally planned and therefore IT does not act with the unfolding social situations and their significances. Consequently, she conceptualizes information technology as an ordering object because of the rigid and planned structure of IT, the necessary organisational structures, with their communication and control mechanisms (Suchman 2007). In this respect, Luhmann (1993), and Lampel and Mintzberg (1996) argue that use of technology becomes a major control and efficiency strategy because of the need for keeping environmental variations to which technology cannot respond at minimum. They argue that this strategy is based on standardisation of work processes and outputs according to the standard ways of working of technological infrastructures (Luhmann 1993; Lampel & Mintzberg 1996). Furthermore, Weick (1990) argues that technology becomes a strategy for action and not just a tool; and so does not only affect practice-level activities of practitioners but also their understandings of the way work is organised.

Thompson (1967) has explained the relation between technology and organising through different types of task interdependencies created by different involvement of technologies in the performance of work. In his study, Thompson (1967) claims that technologies with different characteristics (in terms of the degree of standardisation of the inputs, transformation processes and outputs) create different types of task interdependencies that determine the kind of coordination required. Thompson (1967) argues that the organisational structure should be established based on these different task interdependencies that each requires different kinds of coordination.

Souza and Redmiles (2005) argue that there are many different definitions of interdependencies in the literature, but an overarching definition could be formulated as: “a relationship between two entities that exists because one must interact with the other to accomplish something ‘larger’ than the entities themselves”. Interdependencies have been studied from a number of different perspectives including interdependencies between tasks (e.g. Thompson 1967), parts of design products (e.g. Sosa et al. 2003), organisational parts (e.g. Sanchez & Mahoney 1996), technologies (Bailey et al. 2010) and their combinations (e.g. MacCormack et al. 2012) in order to analyse, relate and manage different frames of complexities inherent in organising. Souza and Redmiles (2005) claim that the idea of interdependencies stems from the assumption that complex systems can be decomposed into parts for making sense of, analysing and managing complexity. Decomposition creates parts and determines the interdependencies between these parts.

In line with this overarching definition, Bailey et al. (2010) define technological interdependence as “technologies’ interaction with and dependence on one another in the course of carrying out work”. Their study explores the effects of technological (in this case, IT that are used in service and knowledge work) interdependencies on organisations and suggests that coordination strategies of task and technological interdependencies are shaped by different considerations (Bailey et al. 2010). For example, they argue that, while in the case of task interdependencies it has been widely claimed that high interdependencies mean more need for coordination, in the case of technological interdependencies, coordination typically focuses on standardizing input and output. However, they also argue that integrating all separate technologies without considering larger occupational and organisational goals could disrupt beneficial, albeit time-consuming coordination efforts (Bailey et al. 2010).

An ongoing discussion around the interdependencies in the field of product design has been the relation between product model and organisational model (e.g. MacCormack et al. 2012). Sanchez and Mahoney (1996) claim that in product design processes, the structure of the product model and corresponding interdependencies create information structures that determine the suitable degrees of coupling between different organisational parts. However, Brusoni and Principe (2001) claim that the relations between product, organisational and knowledge interdependencies are not linear as they have different dynamics. In a similar line of thought, Henderson and Clark (1990) show that knowledge of an organisation is the result of an entangled yet precarious mobilisation of both product and organisational models. Therefore, even if the parts of the product do not change, changing the interdependencies between the parts can result in hardly recognisable and correctable destruction of useful knowledge which is embedded in the routine information procedures and organisational structures of the established organisations (Henderson & Clark 1990). Moreover, although correlations between product and organisational models have been reported (e.g. Frigant & Talbot 2005; MacCormack et al. 2012), Frigant and Talbot (2005) argue that the type, drivers and extent of this correlation are industry specific and need to be explored within the peculiarities of each industry.

Construction design has been studied from the lens of interdependencies and corresponding coordination strategies (e.g. Bølviken et al. 2010); however, studies particularly scrutinizing the role of IT mediation could not be found in this literature. Nevertheless, in a recent study, Knotten et al. (2015) reviews the design management literature from the perspective of interdependencies. In this study, Knotten et al. (2015) conclude that the types of interdependencies and significances of different types of interdependencies shift along the design process and therefore a dynamic approach to manage these is required. They further claim that the new design management approaches, such as BIM, should be reflectively calibrated for the management of various and shifting interdependencies, as they can be counterproductive otherwise (Knotten et al. 2015).

FINDINGS

In this section, two events from practice are described following a general description of the observed project and the coordination activities that took place in it. In the general description of the project and coordination activities, the focus is on the aspects of model coordination and clash detection meetings (MCMs) within which the observed events took place.

The observed project was a design & build educational new built project in which the main contractor undertook the main financial and design risk for the client. The project was ambitious in its use of BIM. At the outset, the project aimed to develop a fully coordinated model consisting of disciplinary models (e.g. an architectural model) with the purpose of using the design model as the baseline for further model-based cost management, scheduling, construction as well as for operation and maintenance purposes. The client had a BIM-literate estates team. Design team members also had working experience in BIM enabled projects as most of them had either worked in the previous phase of the observed project or in other BIM enabled projects. The project had detailed conventions for model based working (e.g. responsibility matrices for the objects in the model, naming conventions for object families etc.) as well as a detailed Employer's Information Requirements document describing the parameters for each of the objects in the model to be provided by specified stakeholders. This information was mainly documented under a BIM protocol which was part of the contract both for the main contractor and the designers. A commercial modelling platform (MP) that had architectural, mechanical-electrical-plumbing (MEP) engineering and structural engineering packages was chosen by the client to be used as the shared BIM platform (i.e. interoperable IT) in the project.

As part of a larger research project, data were collected from this design project mainly through observation of three main types of face-to-face coordination activities over a period of ten months during the detailed design stage. First, fortnightly design coordination meetings (DCM) were observed where specific coordination issues were discussed and general disciplinary updates were shared. Second, some coordination workshops were observed where a specific area of design was coordinated such as furniture and electrical engineering coordination. Third, MCMs were observed where mainly technical issues regarding model development and their extended implications on design were discussed.

Coordinating the Model in MCMs

MCMs were aimed to be held every month, however, they did not have a fixed interval and were mainly scheduled depending on the amount of development of the model since the previous meeting. This was to ensure that the model was meaningfully more developed than the one discussed in the previous meeting where clashes had been identified. In these meetings, two main types of discussions were observed. First, discussions about the implications of working with the model on design development and project management issues took place. This included discussions on the tolerances used in the information models, what was not modelled (i.e. anything below 1/50 scale was not modelled) and whose responsibility it was to coordinate this non-modelled information. Second, detected clashes and their relevance for the design were discussed in MCMs.

The differences between MCMs and other face-to-face coordination meetings were significant. First, the participants of MCMs were largely different from the ones who regularly participated in the DCMs and coordination workshops. Although, the same representatives of the architect attended all types of meetings, the representatives of the mechanical and electrical engineering (M&E) subcontractor and the structural engineer who attended MCMs were different.

Second, the vocabulary used in these meetings, and the strategies followed in order to deal with the issues, were considerably different from the other two types of meetings that were observed. In MCMs, the vocabulary used was very technology-centred with lots of terms adopted from design software and document management system such as objects, categories, worksets, models, names of different file formats, folders, clash detection rules etc. The strategies employed during these meetings were aimed at both understanding the technology and managing the technology for accomplishing the design tasks. The proper functioning of the interoperable IT was one of the main considerations during the discussions that took place in MCMs. This included negotiation of the procedures needed to be followed when working with the different information models, and how specific categories of objects could be turned off. These technology-centred discussions were not only focused on the design stage but also considered the use of the information model in the construction and operation stages. In the following, two events that took place in two different MCMs will be presented which demonstrate the different needs of the participants in the model and the capabilities of the model to work with what people wanted.

Event 1:

> *In the MCM where this event happened, the architect stated that they needed lighting in the M&E model in order to coordinate the suspended ceilings. Following this, the modelling manager of the M&E subcontractor stated that they had taken the decision to model the lighting last. The design manager of the main contractor supported the architect and stated that they had agreed that the M&E subcontractor would model the lighting at this stage. The modelling manager of the M&E subcontractor argued that they previously put considerable effort into modelling the lights at the atrium area and then when the hosting objects were deleted in the architectural model the whole effort was wasted and therefore they decided to model the lights last when the coordination and decisions around the lightings were completed. He argued that the coordination had previously been done by overlaying 2D drawings on the architectural model and this could done like this again. Following this, the architect and the design manager objected to his argument. In response to this, the representative of the M&E subcontractor explained in an upset fashion, that the modelling platform (MP) that was imposed by the client was not geared up for M&E services and they had already needed to create half of the objects including switches, plugs etc. He continued that they had modelled all the equipment in other software where it was much easier to model but exporting it to the MP was problematic. He further argued that his colleagues on the site who were responsible for the installations asked for the systems to be modelled as closed systems with all the elements connected to each other in the information models in order to make sure that the system calculations and design were adequate and finalised. He added that the MP took almost one minute after each and every single change when working with connected and closed systems as the computer needed to re-calculate the whole system again and this made the MP even harder to use efficiently. Moreover, he argued that automated connections between different elements of the system could be wrong and unintentional many times in the MP. Although the design manager of the main contractor added that they did not need closed system in the model and just the geometry of M&E system was enough for their coordination purposes, this was in contrast with the general expectation within the project to use the MP as a full design development tool. At the conclusion of the discussion, the*

modelling manager of the M&E subcontractor told the architect in a calmer voice that they could not provide all the required items in the model in such a short time; but, they could adjust their modelling priorities to the needs of other stakeholders.

Later on in the project, when the ceilings started to be installed on the site, the suspended ceilings needed to be re-documented in a number of 2D drawings with a much finer level of detail and measurements from the site because the installation tolerances on the site made the modelled setting-out details irrelevant.

Event 2:

In the observed project, there was a constant struggle to benefit from automated clash detection. The main challenge was to differentiate between the clashes that resulted from real design problems and the ones that resulted just from poor modelling among the thousands of clashes detected by the MP. The main strategy for handling this was to filter the list of clashes according to the categories of objects and strategically choosing the categories that were more likely to clash because of real design problems rather than the non-detailed modelling due to time constraints. For example, the model identified clashes between the screed on the slab and the structural columns, however, this was marked as "approved" so that it could be neglected in future clash detection exercises because everyone would know that the columns would be in their place well before the application of the screed. Thus, in this context, the ideal of a clash-free model did not mean a model without clashes but rather meant a model with managed clashes. Such a strategy required strictly following naming conventions in the model and also setting up further clash detection rules in the software. However, defining more and detailed rules was not found beneficial as with each new rule added there was an exponential increase in the number of clashes detected. Another implicit strategy was to look for unusually large or low numbers of detected clashes under the filtered categories. In such cases, first the underlying technological causes were questioned (e.g. turned on/off clash detection rules, versions of the uploaded information models etc.). The overwhelming number of detected clashes and uncertainty about the underlying reasons caused tensions during clash detection exercises. On the one hand, the criticisms of the representative of the client and the design manager of the main contractor about the high numbers of clashes were not well received by the designers who were supposed to both develop the design in an iterative way and model the information in clash managed ways. At the same time, the client representative and the design manager of the main contractor kept stating that a clash-free model did not mean a really clash free construction and it was still the responsibility of the designers to coordinate the design with the ultimate aim of having a clash-free design.

In the meeting where this event happened, the architect was criticised for having too many in-discipline clashes between the furniture and internal wall categories which were both owned by the architect. The unexpectedly high number of clashes created a sense of disturbance in the team. The architect claimed that he was aware of these clashes and these did not need to be picked up at that moment because the locations of most of the furniture were not finalised and therefore the architects did not seek to model them clash-free. The design manager of the main contractor further criticised him saying that, then, he should not have exported unfinished worksets for clash detection. The architect objected to this by saying that although clashes *between furniture with internal walls were not relevant at that stage; they needed to check for the clashes between some of the fixed furniture with other disciplines' objects. The architect further stated in an upset fashion that if on site there was an in-discipline clash due to their poor modelling they would be ready to pay for the extra cost and then started to question the purposes of model based design. He criticised the critiques regarding their in-discipline clashes which he thought were normal to have at that stage of the design. As an answer to the architect's statement, the design manager of the main contractor stated that the model was not only a disciplinary document but would also be used for construction and operations and therefore the targets and procedures in place needed to be followed to satisfy multiple requirements from the digital model.*

DISCUSSION

There is a growing awareness that the problematic nature of collaboration in construction design projects is further complicated by the use of interoperable IT. Consequently, there is a need to investigate the ways interoperable IT intervene in the inter-disciplinary relations and affect mutual engagement of different design members. A distinction is drawn here between the "model interdependencies" and the "design interdependencies" in order to create a frame of reference that can separate technology related and design task considerations. Digital integration of data is based upon standardised inputs and rule based connection of data from different designers. Consequently, for the interoperability of IT, user-software interactions need to be structured according to i) the pre-defined ways in which the digital integration operates and; ii) common interaction conventions that need to be established among the users. These requirements create "model interdependencies" that need to be considered by design team members for keeping the IT interoperability up, running and capable of delivering the expected efficiencies (e.g. automated clash detection). However, the design has been perceived, judged and developed by design team members from a great variety of perspectives which are not always in line with or represented by the model interdependencies. In this context, effects of working in a technologically integrated environment are discussed by looking at the interdependencies raised as part of working with the digitally integrated data (i.e. model interdependencies) and other design related interdependencies (i.e. design interdependencies). Technological interdependencies have been previously studied in terms of the interdependencies between separate technologies (Bailey et al 2010; Merschbrok & Wahid 2013). However, in this paper, the term "model interdependencies" is used with a more focused meaning which is limited to the interdependencies as a result of the rule based digital integration of design data.

Both events exposed some model interdependencies that needed to be created and committed to in order to realise some potential advantages of digital integration of design data. In the first event, there were two expected advantages from model based integration of data. The first was better geometrical coordination of ceilings through digital integration of M&E and architectural designs. The second was more accurate and precise M&E system design through the development of the system in the model as a closed system where all parts of the system were digitally related by the modelling software. Model based coordination of ceilings meant model interdependencies between M&E lighting design and architectural ceiling design. However the modelling manager of the M&E subcontractor pointed out the downside of such interdependencies drawing on the event when the ceilings in the atrium (as hosting objects) were deleted by the architect and their effort of modelling was wasted. Moreover, modelling M&E systems as closed systems created model interdependencies between different elements of the modelled system, which in turn resulted in poor computational performance and unintentional automated connections made by the software. Consequently, in practice, due to the perceived "price of documentation" (Dossick & Neff 2014), the modelling manager of the M&E subcontractor was reluctant to use MP as the primary design tool. Additionally, this phenomenon, overall, hindered the timely coordination of basic design interdependency for the coordination of lighting in ceilings. Thus, trying to achieve the perceived benefits of having more precise, accurate and developed information models meant creating more model interdependencies and additional work. However, the expected benefits became even more questionable when the ceilings started to be installed on the site as the installation tolerances required made the detail in the model irrelevant.

In the second event, automated clash detection was based on checking the connections that the software established between different entities in the model (i.e. model interdependencies) against pre-defined rules. However, in practice this needed to be managed by people by filtering thousands of clashes through the object categories used in the model and deciding on the correct detail of the detection rules etc. In other words, the automated detection exercise based on the model interdependencies needed to be reworked as some of the detected clashes were negligible (e.g. just poor modelling) and others were controversial with design interdependencies. For example, the need for clash detecting the fixed furniture with other disciplines without exporting the whole furniture category, which was not completed at the time, caused a conflict between modelling and design interdependencies. The tensions caused by such cases resulted in questioning the purposes of model based working and what should be valued over others. As stated by Jaradat et al. (2013), in such situations it became "increasingly difficult to rely on institutionalized assumptions about who does what, whose view could override others, and who is responsible for what".

The findings suggest that the model interdependencies that were created as a result of working with the integrated data were not always supportive for all members of the project team in their undertakings and caused tensions. The requirements of working with integrated data for realising some expected benefits of the interoperable IT (e.g. error-free calculated closed M&E systems, clash-free model etc.) conflicted with some other considerations of designers. However, resolution of these problems through modifying the IT was largely not possible as the expected efficiency gains of IT were fundamentally based on the controlled and standardised inputs, operations and outputs of the interoperable IT. Previous research into BIM and organising has stated that the effects of digital integration of design data were subject to negotiations between design stakeholders to be settled in practices and enable collaboration (e.g. Whyte & Lobo 2010; Dossick & Neff 2011). This argument is extended here as, although the perceptions of design team members regarding the capabilities of the interoperable IT were shaped through these ongoing negotiations, the interactions between designers and interoperable IT could hardly be modified. The fundamental rigid requirements of interoperable IT and corresponding perceived advantages as a formal control mechanism (especially by the powerful actors such as the main contractor) left limited space for its "appropriation" (Salovaara et al. 2011) through negotiations. Consequently, although practices and interoperable IT mutually shaped each other, this mutual shaping was asymmetrical.

This argument also points to a difference from the findings of Bailey et al. (2010). In line with Bailey et al. (2010), in the observed project, the typical strategy for coordinating the technological (model) interdependencies was the standardisation of inputs and outputs. However, different from Bailey et al. (2010), this research studied an inter-organisational setting and in this setting, consideration of organisational and occupational goals (design interdependencies) in the strategic management of technological (model) interdependencies was limited. Additionally, in this research, conflicts between technological (model) interdependencies and occupational / organisational (design) interdependencies were observed. Even in these cases, conflict resolution through appropriation of IT according to occupational goals was mostly not possible. This in turn mostly led the designers to adjust their working according to the requirements of the interoperable IT.

As argued by Knotten et al. (2015), design management requires coordination of various inter-related considerations with changing effects and significances over the course of the project. In the observed project, the model interdependencies established complex relationships between historically generated design interdependencies and made coordination requirements for the interdependencies harder to grasp and manage in this new situation. It has been found that the know-how of practitioners regarding what to coordinate, why and how, was based on historically established practices and the interdependencies rooted in them. The complex relations between model and design interdependencies made this know-how of inter-disciplinary collaboration irrelevant in this new situation and caused confusions and conflicts. Such confusion was evident in Event 2 when the architect started to question the purpose of the model based working after the criticisms regarding the high number of architectural in-discipline clashes.

This argument is in line with previous studies where it was argued that product, organisational and knowledge interdependencies cannot be linearly mapped (Brusoni & Principe 2001) into simple and unique parts (e.g. M & E systems, architectural systems etc.). The changing interdependencies caused by the introduction of IT suppress useful know-how for skilful recombination of the parts (Henderson & Clark 1990). This previously established know-how was embedded in the previous organisational structure and its routine procedures (Henderson & Clark 1990). In this new situation, the design team members struggled to make sense of the significances of the conflicting requirements and to articulate what should be coordinated and why?

It can be claimed that the industry will eventually develop optimised ways of dealing with interdependencies in this new situation considering both technological and design collaboration requirements in a balanced way (e.g. open systems as proposed by Whyte 2013), thus, enabling interoperable IT supported enhanced collaboration. However this cannot be taken for granted as our findings show that, in practice, conflicting considerations between model and design interdependencies have not always been resolved through negotiated reconciliation but at times were subject to domination of one by the other according to the situations and actors involved. For example, the client's and the main contractor's power positions and their control focused roles over the design made the agenda of keeping the integrated data up and running favourable because of the capabilities of IT mediation as a control strategy. As a result of this, at organisational level, segregation of model related and design development related practices were observed in the project: separate model related meetings, different vocabularies that dominated these meetings, separate model related roles and considerations, separate coordination strategies for the modelled elements and those that were not modelled were present. Consequently, an awareness of this segregation and necessary social and technological precautions are required in order to integrate the efforts of different members of the design team in a complementary way and achieve better design collaboration.

CONCLUSION

There has been a growing awareness that design collaboration has been made more complicated with the use of interoperable IT in BIM enabled projects. This paper has investigated the way interoperable IT intervene in inter-disciplinary relations and affect mutual engagement of different design members. This paper contributes to the research into BIM and collaboration in two ways.

First, it showed that making the distinction between model interdependencies and design interdependencies provides a useful frame of reference for dealing with the complexity of the phenomena. This not only critically questioned the capabilities of IT to mediate in design collaboration but also provided a rich discussion about the incorporation of technology and organising. Further research needs to refine this approach and critically conceptualise model and design interdependencies for using them further for richer analyses.

Second, it extended the understanding of the effects of BIM on collaboration. It was argued that technological considerations and other design related considerations can be in conflict and that the resolution of these conflicts may not be easily achieved due to the fundamental characteristics of interoperable IT and the ways it is framed by powerful actors. Furthermore, historically established know-how for collaboration has been made irrelevant in the changes that take place due to the interdependencies in BIM enabled design projects. At the organisational level, these effects cause a segregation of the organisation into model related practices and design development practices which works against collaboration. Thus, if better design collaboration is actually to be achieved, this segregation needs to be managed and necessary social and technological precautions need to be taken in order to integrate the efforts of different members of the design team in a complementary way.

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